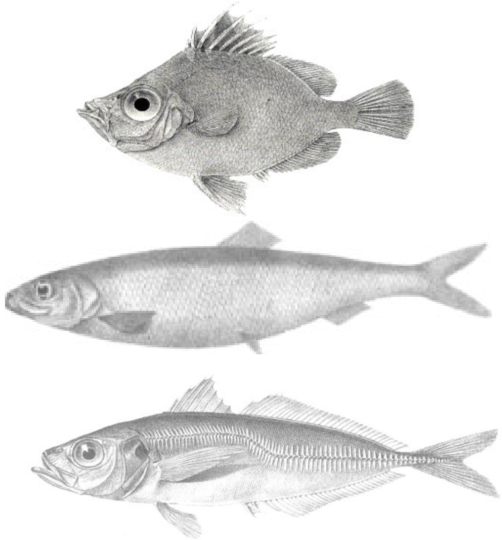
FSS Survey Series: 2020/03

Western European Shelf Pelagic Acoustic Survey (WESPAS)

03 June – 12 July, 2020



Day, 1965

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1 Introduction

The WESPAS survey program is the consolidation of two existing survey programs carried out by FEAS, the Malin Shelf herring acoustic survey, and the boarfish acoustic survey. The Malin Shelf herring acoustic survey has been carried out annually since 2008 and reports on the annual abundance of summer feeding aggregations of herring to the west of Scotland and the north and west of Ireland from 54°N to 58°30'N. The boarfish survey was conducted from 2011 using a chartered fishing vessel and reported the abundance of spawning aggregations of boarfish from 47°N to 57°N. In 2016 both surveys were combined into the WESPAS survey and have been carried out onboard the RV *Celtic Explorer* over a 42-day period, providing synoptic coverage of shelf waters from 47°30'N northwards to 58°30'N.

Age stratified relative stock abundance estimates of boarfish, herring and horse mackerel within the survey area were calculated using acoustic data and biological data from trawl sampling. Stock estimates of boarfish and horse mackerel were submitted to the ICES assessment Working Group for Widely Distributed Stocks (WGWIDE) meeting in August 2020. Herring estimates are submitted to the Herring Assessment Working Group (HAWG) meeting in March every year. Survey performance will be reviewed at the ICES Planning Group meeting for International Pelagic Surveys (WGIPS) meeting in January 2021.

2 Materials and Methods

2.1 Scientific Personnel

Leg	CE20008	CE20008
Dates	03-23 Jun/Jul	23-12 Jun/Jul
Days	21	21
Start	Galway	Galway
End	Galway	Galway
Acou (Chief Sci)*	Turloch smith*	Michael O'Malley
Acou	Sinead O'Brien*	Brendan O'Hea
Acou	Alina Wieczorek	Robert Bunn
Acou	John Power	Eugene Mullins
Bio (Deck Sci)	Marcin Blaszkowski	Dermot Fee
Bio	Grainne Ryan	Emma White
Bio	Sean O'Connor	John Enright
Bio	Roxanne Duncan	Louise Healy
MMO	Cynthia Barile	Maria Perez Tadeo
SBO	Paul Connaughton	Paul Connaughton

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Collect acoustic density measurements of boarfish, herring and horse mackerel within a pre-determined survey area using a split-beam echosounder (EK60) over multiple frequencies
- Determine an age stratified estimate of biomass and abundance for the above target species from survey data
- Collect biological samples from directed trawling on fish echotraces to determine age structure and maturity state of standing stocks
- Take morphometric and genetic samples of individual herring within ICES divisions 6a and 7b, c for stock identification analysis
- Use vertical CTD casts to determine hydrographic conditions and the extent of shelf front regions
- Collect plankton samples using dedicated vertical trawls to determine biomass of zooplankton and the spatial extent of areas of concentration
- Carry out visual surveys to determine the abundance and distribution of marine mammals and seabirds (ESAS)

- Collect Omni sonar (Simrad SU92) data on the aggregation morphology and behaviour of target species

2.2.2 Survey design and area coverage

Survey coverage began in the southern Celtic Sea at 47°30’N (northern Biscay) and worked northwards to 58°30’N (northern Hebrides), including the Porcupine Bank (Figure 1). Area coverage was based on the distribution of catches from the previous surveys (e.g. O’Donnell et al. 2007, 2011).

The survey area was stratified based on acoustic sampling effort strata and geographical stock boundaries. Transect start points were randomised within each stratum. Parallel transect spacing was set at 15nmi (nautical miles) for the main body of the survey and 10nmi in 2 strata to the northwest of Ireland (NW coast and North Malin). Zigzag transects in the restricted Minch area. High-intensity small scale surveys were carried out in specific areas of interest using established methods. Coverage extended from the 50 m contour to the shelf-slope (350 m). An elementary distance sampling unit (EDSU) of 1nmi was used during the analysis of acoustic data throughout the survey area. In total, the planned survey covered 5,531nmi using 58 transects relating to total area coverage of 64,723 nmi².

The survey was carried out from 04:00–00:00 each day to coincide with the hours of daylight when target species are most often observed in homogenous schools. During the hours of darkness, schools generally disperse into mixed-species scattering layers and are not readily available to acoustic sampling techniques.

Survey design and analysis methods for the WESPAS survey adhere to guidelines laid out in the Manual for International Pelagic Surveys (ICES, 2015).

2.3 Fisheries acoustics

2.3.1 EK60 Calibration

All frequencies of the Simrad EK60 were calibrated in June 2020 in Dunmanus Bay. Calibration procedures followed methods laid out in Demer *et al.* (2015). The results of the 38 kHz calibration are provided in Table 1.

2.3.2 Acoustic array

Equipment settings for the acoustic equipment were determined before the start of the survey program, and based on established settings employed by FEAS on previous surveys (O’Donnell *et al.,* 2004, ICES, 2015).

Acoustic data were collected using the Simrad EK60 scientific echosounder. Simrad split-beam transducers are mounted within the vessel’s drop keel and lowered to the working depth of 3.3m below the vessel’s hull or 8.8m below sea surface. Four operating frequencies were used during the survey (18, 38, 120 and 200 kHz) for trace recognition purposes, with the 38 kHz data used to generate the abundance estimate.

While on survey track the vessel is normally propelled using DC twin electric motor propulsion system with power supplied from 1 main diesel engine, so in effect providing “silent cruising” as compared to normal operations. During fishing operations normal two-engine operations were employed to provide sufficient power to tow the net.

2.3.3 Acoustic data acquisition

Acoustic data were recorded onto the hard-drive of the processing unit. The "RAW files" were logged via a continuous Ethernet connection to the vessels server and the EK60 hard drive as a backup in the event of data loss. In addition, as a further back up a hard copy was stored on an external hard drive. Echoview® Echolog (Version 11) live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish schools. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each stratum. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.3.4 Echogram scrutinisation

Acoustic data was backed up every 24 hrs and scrutinised using Echoview® (V 11) post processing software.

The RAW files were imported into Echoview for post-processing. The echograms were divided into transects. Echotraces belonging to one of the target species (herring, boarfish and horse mackerel) were identified and echo integration was performed on the enclosed regions. The echograms were analysed at a threshold of -70 dB and where necessary plankton was filtered out by thresholding at –65 dB.

Partitioning of echograms to identify individual schools was carried out to species level where possible and mixed scattering layers where it was not possible to identify monospecific schools. For scattering layers or mixed schools containing target species the total NASC (Nautical Area Scattering Coefficient) was split using Target Strength (TS) to provide a species specific NASC value. This process was conducted within the StoX program (Johnsen et al., 2019).

The echogram scrutinisation process was carried out by a scientist experienced in scrutinising echograms and with the aid of accompanying trawl catch data.

The allocated echo integrator counts (s_A (NASC, m^2/nmi^2) values) from these categories were used to estimate the herring numbers according to the method of Dalen and Nakken (1983).

The TS/length relationships used predominantly for the survey are those recommended by the acoustic survey planning group based at 38 kHz (ICES, 1994):

Herring	TS = 20logL – 71.2 dB per individual (L = length in cm)
Sprat	TS = 20logL – 71.2 dB per individual (L = length in cm)
Mackerel	TS = 20logL – 84.9 dB per individual (L = length in cm)
Horse mackerel	TS = 20logL – 67.5 dB per individual (L = length in cm)
Anchovy	TS = 20logL – 71.2 dB per individual (L = length in cm)

The TS length relationship used for boarfish is from Fässler et al. (2013):

Boarfish	TS = 20logL – 66.2 dB per individual (L = length in cm)

The TS length relationship used for gadoids was a general physoclist relationship (Foote, 1987):

Gadoids TS = 20logL – 67.5 dB per individual (L = length in cm)

2.3.5 Calculation of acoustic abundance

Acoustic data were analysed using the StoX software package (Johnsen *et. al.,* 2019). A description of StoX can be found here: http://www.imr.no/forskning/prosjekter/stox/nb-no. Estimation of abundance from acoustic surveys within StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990).

2.4 Biological sampling

A single pelagic midwater trawl with the dimensions of 85 m in length (LOA) and a fishing circle of 420 m was employed during the survey (Figure 22). Mesh size in the wings was 2.4 m through to 10 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 25 m and was observed using a cable linked Simrad FS70 netsonde. Spread between the trawl doors was monitored using Scanmar distance sensors, all sensors being configured and viewed through a Scanmar Scanbas system.

All components of the catch from the trawl hauls were sorted and weighed; fish and other taxa were identified to species level. Fish samples were divided into species composition by weight. Species other than the herring/boarfish/horse mackerel/mackerel were weighed as a component of the catch. Length frequency and length weight data were collected for each component of the catch. Length measurements of herring, boarfish, sprat and pilchard were taken to the nearest 0.5 cm below. Horse mackerel and mackerel were taken to the nearest 1.0 cm below. Age, length, weight, sex and maturity data were recorded for individual herring, boarfish and horse mackerel within a random 50 fish sample from each trawl haul, where applicable. Length and weight measurements were taken of a further 100 random fish, and for the remainder a random sub-sample of length only fish were measured until 60 fish in one length class was reached. All herring were aged onboard. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul.

Decisions to fish on particular echo-traces were largely subjective and an attempt was made to target marks in all areas of concentration not just high density schools. No bottom trawl gear was used during this survey. However, the small size of the midwater gear used and its manoeuvrability in relation to the vessel power allowed samples from the bottom to be taken in areas of clean ground.

2.4.1 Herring stock identification

When possible, a sample of 120 herring (>23 cm) were taken for morphometric and genetic analysis from herring in the Malin Shelf area (6a, 7b, c). These fish were processed according to SGHERWAY procedures (ICES, 2010).

2.5 Hydrography and biogeochemical data collection

Oceanographic stations were carried out during the survey at predetermined locations along the survey track using a calibrated SeaBird 911 rosette sampler. Data were collected from 1 m subsurface and 3-5 m above the seabed.

2.5.1 Hydrography and water sampling

Fine scale analysis was not carried during the 2020 due to limitations on the number of scientists that could participate on the survey as a result of the Covid-19 pandemic.

2.5.2 Coloured Dissolved Organic Matter (CDOM)

Analysis was not carried out in 2020 due to the Covid-19 pandemic.

2.5.3 Nutrient sampling

Analysis was not carried out in 2020 due to the Covid-19 pandemic.

2.5.4 Bacteria, Heterotrophic nanoflagellates, Pico and nanoplankton abundance

Analysis was not carried out in 2020 due to the Covid-19 pandemic.

2.5.5 Hyperspectral measurements

In order to more directly compare field data with satellite data, a pair of hyperspectral sensors were mounted above the bridge of the *Celtic Explorer*. The sensor pair incorporated an irradiance and radiance sensor for the purposes of determining the hyperspectral reflectance from the surface of the ocean for comparison to the reflectance measured by the ocean colour satellites.

Particulate absorption of fresh water and seawater can be determined by filtering a known amount of sample through a Glass Fiber Filter (GF/F) and measuring the particulate absorption coefficient $a_p(\lambda)$ concentrated on the filter. This technique is called quantitative filter technique (QFT) and corrects for the pathlength amplification, an effect of scattering. Measurements were made shipboard using a QFT-1 filter holder (WPI) after filtering 200-1000 mL of seawater through a 25 mm GF/F filter. An Ocean Optics Maya spectrophotometer was coupled to the QFT-1 using 600 µm diameter fibre optical cable with a DH mini light source.

2.5.6 Chlorophyll measurements

Analysis was not carried out in 2020 due to the Covid-19 pandemic.

2.6 Zooplankton and jellyfish sampling

2.6.1 Zooplankton

Zooplankton sampling was carried out alongside CTD stations. A weighted 1 m diameter Hydro-bios ring net was used with a 200 µm mesh size and the net was fitted with a Hydro-Bios® calibrated mechanical flow meter to determine the volume of water filtered. Vertical plankton tows were carried out to within 5 m of the seabed for stations where total depth was less than 100 m and to a 100 m maximum for all other stations depths.

Single tow stations samples were split in 50:50 for wet and dry processing. Sample splitting was carried out using a Hydro-Bios® sample splitter. The wet component was fixed for further analysis back at the lab. Fixing was carried using a 4% fix volume of buffered formalin.

Dry processing was carried out with each sample filtered through 2000 µm, 1000 µm and 125 µm sieves. For the largest gauge sample (2000 µm) including jellyfish and or krill volume displacement (ml) was measured using a graduated cylinder. For finer gauge samples (1000 and 125 µm) dry weight analysis was carried out. Samples were transferred to petri-dishes and dried onboard (70 °C oven) for a minimum of 24 hrs before sealing and freezer storage. Back in the lab dry weight analysis was carried out on defrosted frozen samples using a Sartorius MSE225S-000-DA fine scale balance (uncertainty of +/- 0.00016 g).

2.6.2 Jellyfish

Analysis was not carried out in 2020 due to the Covid-19 pandemic.

2.7 Marine mammal and seabird surveys

2.7.1 Marine mammal abundance and distribution

The cetacean survey was conducted from the 14/06/19 to the 10/07/19 using a team of two marine mammal observers (MMOs), with one cetacean observer deployed per survey leg. To prevent MMO fatigue and optimise the validity of the data, survey effort was carried out in two-hour shifts, with a break of one hour between shifts.

Cetacean watches were conducted using a standard single platform line transect survey design while the vessel was travelling at a consistent speed and heading. When the vessel was stationary at oceanographic stations, cetacean watches were conducted using a standard single platform point sampling survey design. Visual watches were undertaken from the vessel's crow's nest, located 17.45 m above sea level, during all daylight hours, when weather conditions permitted. During periods of unfavourable weather conditions, observations were carried out from the bridge (10.63 m above sea level).

Survey effort was concentrated in periods of sea state 6 or less, and in moderate or good visibility. Survey effort conducted outside of these parameters was conducted at the discretion of the observers. Survey effort for cetaceans was concentrated within an arc of 60^{o} either side (i.e., to port and to starboard) of the vessel's track-line but all sightings to 90^{o} both side of the track-line and further aft were also recorded. Searching for cetaceans was predominantly done with the naked eye, however, Nikon Prostaff 7 8x42 binoculars and a Canon EOS 7D DSLR camera with a Sigma 100-400 mm zoom lens was used to confirm species identification and group size, and assess behaviour. Survey effort was also carried out during hauls and when at CTD stations.

The Cybertracker (http://www.cybertracker.org/) data collection software package (Version 3.501) was used to collect all positional, environmental and sightings data, and save it to a Microsoft Access database. Positional data was collected using a portable GPS receiver with a USB connection and recorded every 5 seconds.

Each line transect was assigned a unique transect number, and a new transect was started anytime the vessel activity changed (i.e. changing from on-transect to inter-transect). Each subsequent sighting was also assigned to this unique transect number.

Environmental data was time-stamped and recorded with GPS data at the beginning and end of each line transect. Environmental data was recorded at least every 15-30 minutes, or sooner if there was a change in environmental conditions. Environmental data recorded included; wind speed, wind direction, sea state, swell, visibility, cloud cover and precipitation. All data entry was time stamped by Cybertracker and saved in the Access database.

The distance of each sighting from the ship was estimated using a fixed interval range finder (Heinemann, 1981), while the bearing from the ship was estimated with an angle board. This data, along with data such as species identification, group size, composition, heading, sighting cues, surfacing interval, behaviour and any associations with birds or other cetaceans was also recorded on the time stamped Cybertracker sighting record page. Where species identification could not be confirmed, sightings were recorded at an appropriate taxonomic/confidence level (i.e. probable, possible, unidentified whale, unidentified dolphin etc.). Auxiliary and incidental sightings were also recorded.

Ancillary data such as line changes, changes in survey activity (e.g. fishing/CTD cast) and fishing vessel activity were also recorded.

2.7.2 Seabird abundance and distribution

The seabird survey was conducted from the 14/06/19 to the 24/07/19 using a team of two seabird surveyors per survey leg. The lead seabird observer conducted visual survey effort, while the other seabird observer was responsible for data collection and recording. The observer’s survey effort was maximized and optimized during periods of sea state less than or equal to sea state 6 and with visibility of greater than 300m. Additional visual point sampling (e.g., at oceanographic sampling stations or fishing stations) and incidental recording were also employed; however, line transect survey effort was prioritised by the observer. Seabird watches were conducted using a standard single platform line transect survey design while the vessel was travelling at a consistent speed and heading. Observations for seabirds were conducted from the monkey island (deck height 12 m above sea level) or the bridge (deck height 10 m above sea level). Observations were conducted from the monkey island preferably, however, as in previous surveys aboard the RV *Celtic Explorer*, access to the monkey island was dependent on weather conditions.

The data collection methodology was based on that originally proposed by Tasker *et al.* (1984) with later adaptations applied to allow correction factors to be applied for missed birds (Camphuysen *et al*., 2004). The method employed used a single platform line transect survey design with sub-bands to survey birds associated with the water, while flying birds were surveyed using a ‘snapshot’ technique. Observer effort was concentrated in a bow-beam arc of 90^{o} to one side (i.e., to port or starboard) of the vessel’s track-line, however, all seabirds observed outside this area were also be recorded.

Survey effort for seabirds associating with the water were concentrated within a survey strip of 300m running parallel and adjacent to the vessels track-line and extending to the horizon. All birds surveyed within this region were be recorded as 'in-transect' and assigned to one of four distance sub-bands (A: 0-50 m, B: 50-100 m, C: 100-200 m, D: 200-300m) according to their perpendicular distance from the track-line. This approach allows for the evaluation of biases caused by specific differences in detection probability with increasing distance from the track line (Camphuysen *et al.* 2004). Seabirds occurring outside of this survey strip were recorded as 'off-transect' and assigned to separate sub-band (E: >300 m). The perpendicular distance to an animal was estimated using a fixed interval range finder (Heinemann, 1981), ensuring each animal is allocated to the correct distance sub-band.

Flying birds were surveyed using 'snapshots', where instantaneous counts of flying birds within a survey quadrant of 300 m x 300 m were conducted. The periodicity of these 'snapshots' was vessel speed dependent but timed to allow counts to occur as the vessel passes from one survey quadrant to the next. This method minimises biases in counts of flying birds relative to the movement of the vessel (Pollock *et al.,* 1997, Camphuysen *et al.* 2004).

Seabirds remaining with the vessel for more than 2 minutes were deemed to be associating with the vessel (Camphuysen *et al.* 2004) and were recorded as such. Seabirds seen associating with other vessels (i.e. fishing vessels) were also recorded as such.

Searching for seabirds was done with the naked eye, however, Leika Ultravid 8x42 HD binoculars were used to confirm parameters such as species identification, age, moult, group size and behaviour (Mackey *et al.* 2004). A Canon EOS 7D Mark II DSLR camera with a Canon EF 100-400 mm F4.5-5.6 IS II USM telephoto lens was used to visually document other information of scientific interest. Data was also collected on all migratory/ transient waterfowl and terrestrial birds encountered.

The Cybertracker (http://www.cybertracker.org/) data collection software package (Version 3.501) was used to collect all positional, environmental and sightings data, and save it to a Microsoft Access database. Positional data was collected using a portable GPS receiver with a USB connection and recorded every 5 seconds.

Each line transect was assigned a unique transect number, and a new transect was started anytime the vessel activity changed (i.e. changing from on-transect to inter-transect). Each subsequent sighting was also assigned to this unique transect number.

Environmental data was time-stamped and recorded with GPS data at the beginning and end of each line transect and also as soon as any change in environmental conditions occurred. Environmental data recorded included; wind speed, wind direction, sea state, swell, visibility, cloud cover and precipitation.

Each sighting was time-stamped and recorded with GPS data using Cybertracker. Sighting data such as; species identification, distance band, group size, composition, heading, age, moult, behaviour and any associations with cetaceans or other vessels were also recorded on the time stamped Cybertracker sighting record page. Where species identification could not be confirmed, sightings were recorded at an appropriate taxonomic level (i.e. large gull sp., Larus sp., Commic tern, etc.).

Ancillary data such as line changes, changes in survey activity (e.g. fishing/CTD cast) and fishing vessel activity were also recorded.

3 Results

3.1 Malin Shelf herring (6.a.S, 7.b, c and 6.a.N south of 58°30'N)

3.1.1 Biomass and abundance

Herring	Abund ('000)	Biomass (t)
Total stock (TSB)	3,615,795	370,048
Spawning stock (SSB)	1,138,327	177,493

The Malin Shelf Herring total stock biomass (TSB) was 370,048 t and total stock numbers (TSN) was 3,615,795,000 (Table 3). The spawning stock biomass (SSB) was 177,493 t and spawning stock numbers (SSN) was 1,138,327,000. The CV for the survey was 0.25.

The Malin Shelf survey area was divided into 6 strata representing a total area coverage of 32,162 nmi^2 (Figure 2 & Table 5). A breakdown of herring stock abundance and biomass by age, maturity and stratum is detailed in Table 3 and Figure 4. The Malin Shelf survey time series is provided in Table 4.

3.1.2 Stock distribution

In the Malin Shelf area 8 hauls contained >50% herring by weight of catch (Figure 1 and Table 2). A total of 965 echotraces were assigned to herring compared to 115 in 2019 in this area.

The area covered by the RV *Celtic Explorer* was similar to the 2019 survey. The area of 6.a.N to the north of 58°30'N was covered by RV Scotia in 2020; the overall estimate of the survey for the stock assessment of herring in 6.a will therefore be complete when both surveys are combined at WGIPS 2021. Herring were distributed in all of the six strata (Table 5). A total of 261 EDSUs (1nmi. long) contained herring in the Malin Shelf survey area in 2020, compared to 58 in 2019. This included a number of high NASC value EDSUs, with areas of high density occurring to the north and west of Tory Island, north of the mouth of Lough Swilly in 6.a.S, and around of St. Kilda in 6.a.N (Figure 3). Herring were again found in large numbers south of 56 ˚N in 2020, similar to the historical distribution of herring found during this time series. There were adult herring distributed south of the 56°N in 2020 similar to 2019, herring had been largely absent for a number of years prior to this. Herring schools were predominantly found in midwater, fast-moving pillars and in dispersed marks in close proximity to the seabed (Figures 11g, 11h, 11j, 11l and 11m). Overall the stock was distributed throughout a similar area to 2019 but in greater numbers, especially immature fish (Figures 3 and 4). The distribution of herring during the survey period is usually observed in 3 particular regions; north of 57°N (west of the Hebrides), between 56-57°N (south and west of Barra Head) and south of 56°N (north and west of Donegal and Stanton Bank). The survey in 2020 largely followed this distribution.

3.1.3 Stock composition

A total of 934 herring were aged from survey samples with 4,371 length measurements and 1,734 length-weights recorded. Herring age samples ranged from 0-9 year olds (Table 3 & Figure 4). A further 720 herring were processed for morphometric analysis under SGHERWAY protocols (ICES 2010) in 2020; from hauls 23, 25, 26, 28, 31, and 32. Samples of flesh (~1cm^3) were also taken from 933 fish for genetic analysis from herring in hauls 22, 23, 25, 26, 27, 28, 31, and 32.

The 2020 survey estimate was dominated by 1-wr (24% TSB and 43% TSN) and 2-wr (32% TSB and 29% TSN) (Table 3). The third most dominate age group was 3-wr herring contributing 19% to the TSB and 14% to TSN. Combined these three age classes represented 75% of TSB and 86% of TSN.

Maturity analysis of herring samples in 2020 indicated overall 48% of herring (TSB) were mature. In 2019, 79% of herring were mature. Maturity analysis by age class showed that 28% of 2-wr, 65% of 3-wr fish, and 100% of fish of 4-wr and older were mature (Table 3).

3.2 Boarfish

3.2.1 Biomass and abundance

Boarfish	Abund ('000)	Biomass (t)
TSB estimate	9,893,782	399,872
SSB estimate	5,797,924	357,871

Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 399,872 t and 9,893,782,000 individuals (CV 0.34) respectively.

The boarfish survey area was divided into five strata representing a total area coverage of 51,489 nmi^2 (Figure 2). A breakdown of boarfish stock abundance and biomass by age, maturity and stratum is detailed in Table 6 & 7 and Figures 5 & 6. The boarfish survey time series is provided in Table 8.

3.2.2 Stock distribution

A total of 35 trawl hauls were carried out during the survey (Figure 1), with 10 hauls containing >50 % boarfish by weight (Table 2).

A total of 928 echotraces were assigned to boarfish compared to 667 in 2019. Boarfish were observed in all survey strata (Table 7). Geographical distribution was comparable to previous years with the greatest biomass occurring in the Celtic Sea (65.6 % of total biomass), followed by the Irish west coast (21.9%). Within the Celtic Sea, the highest density of fish was observed in the southern survey area, south of 50°N, as in previous years (Figure 5). For third second consecutive year, the southernmost transects were dominated by clusters of high density juvenile boarfish aggregation occurring predominantly above the thermocline (Figure 11a). In the mid Celtic Sea (north of 50°N), aggregations of mature boarfish were observed (Figure 11b) as well as aggregations of juvenile fish.

The west coast stratum ranked second contributing 21.9% of total biomass (17.5% abundance) and is in line with previous observations. Distribution within this stratum could be subdivided into two clusters; one north of 53°N and the other off the south-west coast. During the years 2018-2019 a near absence of boarfish was reported along the southwest coast of Ireland (51°-52°N). In 2020, a near absence of boarfish was observed further north between 52-53°N.

The distribution of boarfish north of 55°N, was characterised by medium density aggregations of fish occurring in close proximity to the shelf edge. Such aggregations were observed almost continuously to the northernmost transect of the survey (Figure 5). The distribution of boarfish in the northernmost survey latitudes is a common occurrence within the recent times series.

3.2.3 Stock composition

A total of 651 boarfish were aged from survey samples in addition to 3,091 length measurements and 1,204 length-weights recorded. Boarfish age samples ranged from 1-15+ years (Table 6 & Figure 6). The age structure of the stock was determined using an established age length key.

The 15+ year age classes dominate the 2020 estimate contributing over 33.3% of TSB and 16.6% of TSN (Table 6). The 8-year-old (11.5% TSB and 8.9% TSN) and 9-year – old age classes (10.8% TSB and 7.3% of TSN) ranked second and third respectively. Combined, the 15+, 8 and 9-year age classes represent 55.6% of TSB and 32.8% of TSN.

Maturity analysis of boarfish indicated 89.5% of observed biomass was mature (58.6% for abundance). The contribution of immature fish to the standing stock estimate in 2020 is higher than in 2019, which in turn was high than in 2018. This trend can be attributed to the presence of increased numbers of 0, 1, 2 and 3-year-old year classes that are yet to the recruit to the spawning stock. Maturity analysis of survey samples by age class showed that 1% of 3-year-old fish were mature (3% in 2019), rising to 100% for fish four years and older (Table 6).

3.3 Horse mackerel

3.3.1 Biomass and abundance

Horse mackerel	Abund ('000)	Biomass (t)
TSB estimate	264,314.0	47,553.4
SSB estimate	221,059.0	43,523.6

Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 47,553 t and 264,314,000 individuals (CV 0.31) respectively.

The horse mackerel survey area was composed of 7 strata relating to an area coverage of 58,632 nmi^2 as shown in Figure 2. A breakdown of horse mackerel stock abundance and biomass by age, maturity and stratum is detailed in Tables 9 & 10 and Figures 7 & 8. The biomass of horse mackerel is 44% lower in terms of biomass and 21% in terms of abundance compared to 2019.

3.3.2 Stock distribution

A total of 35 trawl hauls were carried out during the survey (Figure 1), with no hauls containing >50% horse mackerel by weight. Twelve hauls contained horse mackerel (Table 2).

A total of 136 echotraces were assigned to horse mackerel. Horse mackerel were observed along the west and northwest coast of Ireland and in the Celtic Sea, where the bulk of the standing stock was located (Figure 7). No schools were located within the Porcupine Bank stratum. Observations of horse mackerel along the west coast and Celtic Sea were comparable to 2019 in terms of geographical distribution and the number of schools (120 in 2019, 136 in 2020). However, the overall acoustic density was lower, as reflected in the overall standing stock biomass.

Of the 7 strata surveyed, three reported observations of horse mackerel. The Celtic Sea stratum contained the largest proportion of biomass observed (55.1% of TSB), followed by the west coast (33.4%) and southern Hebrides (11.4%). Overall, the composition of horse mackerel aggregations was considered to be of low density with no of medium and high density schools detected. Biological samples were taken only as part of mixed species catches.

3.3.3 Stock composition

A total of 257 horse mackerel were aged from survey samples in addition to 231 length measurements and 22 length-weights recorded. Horse mackerel age samples ranged from 2-16 years (Table 9 & Figure 8). Age structure of the stock was determined using an age length key from constructed from the previous years aged survey samples.

The 3-year-old fish (2017-year class) dominated this year's survey estimate representing 21.8% of TSB and 34.8% of TSN (Table 9). The 4-year-old fish ranked second representing over 19.3% of TSB and 19.5% of TSN (Table 9). Seven-year-old fish were ranked third contributing 17.3% to TSB and 13.3% to TSN. Combined these three age classes represented 58.3% of TSB and 67.6% of TSN.

Maturity analysis of horse mackerel samples indicated 91.5% of the total stock biomass was mature and over 83.6% of total abundance. Maturity analysis by age class showed that no 2-year-old fish were mature, and all 3-year-old fish and older were mature and fully recruited to the spawning stock (Table 9). The number of 2-year-old fish sampled was low and may therefore not fully reflect the actual spread of maturities in this transitional year class.

3.4 Celtic Sea herring (7g and j)

3.4.1 Biomass and abundance

CS Herring	Abund ('000)	Biomass (t)
Total stock	682,177.0	43,462.0
Spawning stock	22,468.0	2,551.8

The estimate of Celtic Sea (CS) herring TSB (total stock biomass) and relative abundance (TSN) estimates were 46,365 t and 442,986,000 individuals (CV 0.79) respectively.

The herring survey area was composed of a single stratum in the Celtic Sea, representing an area of over 27,934 nmi² and was surveyed using the standard survey transect spacing of 15 nmi. No high intensity surveys were carried out for herring in 2020. A breakdown of CS herring stock abundance and biomass by age, maturity and stratum is detailed in Tables 12 & 13 and Figures 9 & 10.

Estimates of Celtic Sea herring biomass are not comparable to the stock index survey carried out in October and should not be used for comparative purposes due to differences in survey design and coverage. Stratum area coverage during WESPAS is significantly larger and is not scaled to the October survey area.

3.4.2 Stock distribution

Forty echotraces of various sizes and acoustic density were assigned to herring in the Celtic Sea and herring were sampled in four targeted hauls, two of which contained over >50% by weight (Table 2). Herring were observed in two areas; in the western and eastern Celtic Sea (Figure 11e-f and Figure 9).

3.4.3 Stock composition

A total of 312 CS herring were aged from survey samples in addition to 847 length measurements and 300 length-weights recorded. CS herring age samples ranged from 1-8 winter rings (wr) (Table 12 & 13 and Figure 10). Age structure of the stock was determined from survey aged otoliths.

Two winter ring fish dominated the total estimate, representing 63% of total biomass and over 67% of total abundance (Table 12). Three winter ring fish ranked second contributing 25.2% of the total biomass and 22.8% of total abundance. Combined these two immature ages classes represented over 88% of total biomass and over 90% of total abundance (Figure 10). In terms of age structure, the survey has tracked the strong 2018-year class successfully. The 2018-year class was first identified as a candidate strong year class during the Celtic Sea herring acoustic survey in October 2018 as 0-group fish and were observed during WESPAS 2019 as 1-wr fish. During the Q4 CSHAS 2019, although present in survey samples and the fishery, this age class was not observed in the numbers expected during the Q4 survey.

Maturity analysis of Celtic Sea herring samples indicated 48% of 2-wr fish were mature, rising to 96% of 3-wr fish. Maturity analysis indicated over 64% of the TSB was mature and 58% of TSN (Table 12).

3.5 Hydrography and biogeochemical sampling

3.5.1 CTD sampling

In total, 76 CTD casts were carried out (Figure 12). Horizontal temperature and salinity maps for the survey area are provided for depths 5 m, 20 m, 50 m and at the seabed in Figures 13-16 respectively.

Surface waters, above the thermocline, showed a similar pattern of salinity in the 5 and 20 m depth profiles. Slightly lower salinity waters were found around coastal fringes and in the eastern Celtic Sea and are likely influenced by terrestrial run-off (Figures 13

&14). The temperature profile of surface waters showed the highest values in the south and in the eastern Celtic Sea as expected. Thermocline depth varied between sampling location ranging from of 35-50 m in the most part. Below the thermocline, (Figures 15 & 16), a pool of colder water (~10°C) dominates the Celtic Sea, southwest and western coastal margins of Ireland. This area of cold water in the Celtic Sea continues northwards to the 56°N line of latitude (Figure 16).

Comparing hydrographic conditions (derived from near bottom temperature profiles) with the acoustic observations of herring, it appears that as in previous years herring distribution was closely aligned with the 10 ºC isotherm (Figure 17). Distribution appeared less influenced by salinity than temperature and is in agreement with previous years' observations during summer feeding phase.

For boarfish thermal preference appears as important as salinity (Figure 18). The greatest density of boarfish is aligned with full strength seawater and off the west coast this occurs on the oceanic side of the Irish Shelf Front. In the southern survey area, in recent years' immature boarfish have been observed in increasing numbers and indications are that temperature may be an important factor, amongst others, within this nursery area.

Horse mackerel (Figure 19) distribution appears to follow a similar pattern to that of boarfish in that full strength seawater is the preferred habitat with a variable temperature distribution profile from north to south.

3.5.2 CDOM measurements

No sampling undertaken.

3.5.3 Nutrient sampling

No sampling undertaken.

3.5.4 Pico/nano plankton sampling

No sampling undertaken.

3.5.5 Hyperspectral analysis

During this year's survey, *in situ* reflectance data were again collected using a pair of hyperspectral sensors which were mounted above the bridge of the *Celtic Explorer*. This data allows comparison with satellite reflectance data used in ocean colour estimates of chlorophyll and primary productivity.

Ongoing work will compare shipboard reflectance chlorophyll estimates with the satellite and in situ observations and examine the influence of the particulate absorption (QFT-1 measurements) on the results.

3.5.6 Chlorophyll measurements

No sampling undertaken.

3.6 Zooplankton biomass and jellyfish abundance

3.6.1 Zooplankton

Plankton samples were collected at 59 stations during the survey. Zooplankton biomass (dry weight) by station was more sporadic, and similar to 2016, compared to the period 2017-2019 where dry weight appeared more uniform (Figure 20). The period 2017-2019 coincides with the increase in numbers of immature fish (herring/boarfish/horse mackerel) of the 2017- 2019 year classes. However, the two cannot be directly linked.

3.6.2 Jellyfish

No sampling undertaken.

3.7 Marine mammals and seabirds

3.7.1 Marine mammal visual abundance survey

In total, 297 hours and 26 minutes were spent on effort during the survey with a corresponding distance of 7,37 8km (144 hours 04 minutes and 3,528 km during the Leg 1 and 153 hours 22 minutes and 3,850 km during leg 2).

Environmental conditions encountered were recorded at a total of 1,208 stations (627 and 581 during Leg 1 and Leg 2 respectively) Sea state ranged from 0 to 6, with effort carried out under sea state 6 for only 4 % of the time during Leg 2. Effort was conducted under favourable sea conditions (i.e. sea state from 0 to 3) during 77% and 70% of the time during Leg 1 and Leg 2 respectively. Visibility ranged from 1 (less than 1 km) to 6 (more than 20 km). Visibility was overall favourable during the time spent on effort, recorded as less than 5 km during 4% and 11% of the effort for Leg 1 and Leg 2, respectively. Swell height ranged from 0 to 3, with swell 0 recorded 15% of the time on effort on Leg 2. The predominant swell was 1, recorded for 83% (Leg 1) and 57% (Leg 2).

The seven odontocete species encountered were common dolphin (Delphinus delphis), bottlenose dolphin (Tursiops truncatus), harbour porpoise (Phocoena phocoena), long-finned pilot whale (Globicephala melas), Risso's dolphin (Grampus griseus), white-beaked dolphin (Lagenorhynchus albirostris) and Atlantic white-sided dolphin (Lagenorhynchus acutus) with a total of 108 sightings of 2,360 individuals recorded (Table 14 & Figure 21).

Common dolphins were by far the most commonly encountered and abundant species in both legs, accounting for 68 sightings of 1,922 individuals in total. Common dolphins also presented the largest group size, with a group of up to 250 individuals encountered (Table 14). Bottlenose dolphins presented the second most frequently sighted odontocete species (with 15 sightings recorded of 259 individuals), followed by harbour porpoises (seven sightings of ten individuals), Risso's dolphins (five sightings of 25 individuals) and Atlantic white-sided dolphins (four sightings of 48 individuals). Long-finned pilot whales (two sightings of 55 individuals) and white-beaked dolphins (one sighting of two individuals) were the species less frequently encountered. Long-finned pilot whales, Atlantic white-sided and white-beaked dolphins were only recorded during Leg 2.

Minke whale (Balaenoptera acutorostrata) was by far the most frequently encountered species of mysticetes during both legs of the survey, with a total of 57 sightings of 61 individuals. These were followed by fin (Balaenoptera physalus) and humpback whales (Megaptera novaeangliae) with 33 and 11 sightings of 38 individuals and 19 individuals, respectively. Humpback whales were only sighted during the course of Leg 1. Mysticetes were encountered in groups of between one to four individuals (Figure 11).

The only species of pinnipeds observed in both legs were grey seals, with a total of seven animals in seven different sightings (Figure 21).

Apart from marine mammals, 12 sightings of three different species of megafauna were recorded (Table 14). Sunfish (Mola mola) was the species more commonly encountered with nine sightings of 13 individuals. A single individual of basking (Cetorhinus maximus) and blue shark (Prionace glauca) were also recorded.

3.7.2 Seabird abundance and distribution

In total, 271 hours and 5 minutes of survey effort was conducted over the course of WESPAS 2020. Of this, 211 hours and 54 minutes of survey effort were conducted using a line transect methodology, while 51 hours and 46 minutes of effort were conducted using the point sampling methodology. A further 7 hours and 25 minutes of effort were conducted as a casual watch.

A total of 5,750 seabird sightings were recorded throughout the survey, totalling 65,242 individuals (Table 15). In total, 21,468 seabirds were recorded as “in transect”, while 43,774 were recorded “off transect”. The species encountered included 31 species’ or species groups from 10 families. A further 10 sightings of terrestrial/migratory birds were also recorded, comprising of 71 individuals (Table 15).

Gannet (*Morus bassanus*) were the most frequently encountered species, recorded on 2048 separate occasions, accounting for 35.6% of all sightings. Gannet sightings comprised of a combined total of 16,681 individuals (25.6% of all individuals) making gannet the second most abundant species on the survey. However, of these, only 3,899 individuals were recorded as ‘in transect’.

Manx shearwater (*Puffinus puffinus*) were the most abundant species recorded on the survey with 26,098 individuals recorded. These individuals accounted for 40.0% of all individuals recorded, and were recorded during 553 separate encounters (9.6% of sightings), making them the fourth most frequently sighted species. Of the 26,098 individuals recorded, 12,381 individuals were recorded as ‘in transect’.

Fulmar (*Fulmarus glacialis*) were the second most frequently sighted and the third most abundant species accounting for 1,344 sightings (23.3% of all sightings) and comprising of 14115 individuals in total (21.6% of all encountered individuals.) Of these, 1901 individuals were recorded as ‘in transect’.

European storm petrel (*Hydrobates pelagicus*) were the third most frequently sighted and the fourth most abundant species accounting for 555 sightings (9.7% of all sightings) and comprising of 3628 individuals in total (5.7% of all encountered individuals.) Of these, 1,083 individuals were recorded as ‘in transect’.

A number of terrestrial/ migratory birds were encountered during the survey. A total of 10 sightings of terrestrial/ migratory bird species were recorded during the survey. These sightings comprised of 71 individuals from 8 species. Notable sightings included a spotted flycatcher (*Muscicapa striata*), a black redstart (*Phoenicurus ochruros*), a white-tailed eagle (*Haliaeetus albicilla*), and a group of 4 tufted duck (*Aythya fuligula*).

4 Discussion and Conclusions

4.1 Discussion

The objectives of the survey were carried out successfully and as planned. Overall, weather conditions were generally good throughout the survey, with a moderate amount of time lost (<12 hrs on leg 1 and ~36 hours on leg 2) due to poor weather. A total of 17 zooplankton stations were lost due to high winds.

Malin Shelf herring distribution was concentrated in an area to the north and west of Tory Island (south of 56˚N) and north of the mouth of Lough Swilly/west of Isle of Islay in 6.a.S and to the west of the Hebrides in 6.a.N, particularly around St. Kilda (Figure 3). There was an approximately 2.5-fold increase in overall the SSB in 2020 compared to 2019 in the survey area (O'Donnell et al 2020), driven mainly by an increase in immature fish. The final estimate of herring in 6.a (combined 6.a.S, 7.b,c and 6.a.N) will be completed by including the biomass and abundance of herring from the survey of 6.a.N to the north of 58˚30N and west of 4˚W carried out by the RV Scotia. This final estimate will be presented at WGIPS in 2021. There have been issues with stock identification and containment with this survey in the past, particularly in relation to the boundary of the North Sea stock at the 4˚W line, and the distribution of herring north and south of the 56˚N line (6.a.N/6.a.S), for example. Fish distributed either side of these boundary lines influence the respective survey estimates annually. There is genetic and morphometric work ongoing to try to better split the survey into 6.a.N and 6.a.S components and it is hoped that this will be possible in the future.

There were good signs of young immature herring in the Malin Shelf area, particularly 1-wr and 2-wr herring distributed in 6.a.S in the area to the north of Lough Swilly/west of Islay and in an area to the west of the Butt of Lewis. This survey is not generally a good design for juvenile herring but immature fish can show up in some years. The age profile of survey samples in 2020 is dominated by 1-wr, 2-wr and 3-wr herring dominate the survey (75% in terms of biomass, and 86% in terms of abundance). The CV estimate for the 2020 survey is lower than in 2019 (0.25 compared to 0.37); more comparable to previous years in the time-series. This was a due to an increased and better spread of herring marks across transects and strata in 2020.

The geographical distribution of boarfish was comparable to earlier years in the time series; with a clusters of individual schools concentrated towards the shelf margin. Overall, the acoustic density and number of echotraces of boarfish was significantly higher than observed in 2019 considering comparable, if not slightly reduced, survey effort (2019 to 2020: -7% transect effort and 3-% area coverage).

Trawl sampling was not possible in the early days of the survey due to naval exercises within the French EEZ. The southernmost transects, around northern Biscay, have in recent years become increasing important as a nursery area for immature boarfish. Historically, this area has also contained a high abundance of mature fish. Directed trawl sampling is important not only to identify species composition of echotraces but also to determine the age, length and maturity of individuals. This becomes increasingly important in areas where immature and mature mixing occurs. Trawl samples from adjacent areas were applied during the analysis.

In the southern Celtic Sea and northern Biscay area (47°N- 49°N), the presence of immature boarfish has seen to increase in recent years. The northern latitudes are shown to contain spawning boarfish during the survey, indicating preferred spawning habitat are being met across years and boarfish are likely year-resident in the area.

During this year's survey, the size and acoustic density of schools was higher than previously observed and no doubt contributed to the increased overall biomass reported. Total biomass and total abundance were over double that observed in in 2019 and observations of boarfish increased significantly for all survey strata with the exception of the Porcupine Bank, where a 50% reduction was observed (2019: 27,824t vs. 2020: 12,787t). The largest increase was observed in the Celtic Sea with the TSB estimate seeing a threefold increase on 2019 (2019: 78,530t vs. 2020: 262,339t). A threefold increase in observed biomass was also reported from the southern Hebrides (2019: 7,361t vs. 2020: 21,037t), while the west coast strata saw an increase of 74% (2019: 50,201t vs. 2020: 87,406t).

The Celtic Sea strata, as in previous years, contributed most to the TSB (65.6%), followed by the West coast (21.9%) and the northern strata; South and western Hebrides (5.3 and 4.1% respectively).

The oldest (15+ year) cohort remain the largest contributors to the stock biomass and abundance within the time series. Seven, eight and nine-year-old fish (2013, 2012 and 2011 year classes respectively) are important cohorts within the stock and have track well through the survey index. From 2018 onwards, the contribution of immature fish has increased as strong year classes continue to emerge. Within the 2020 survey, this is represented by the 2017, 2018 and 2019 year classes. Added to this are the 0-group fish of 2020, which at this point indicate the continuation of this period of good recruitment for this stock. Immature fish from the 2020 estimate represent over 41% of the TSN and 10.5% of TSB.

Accurate age determination remains an issue due to the use of a historic age length key. Aging actual survey caught fish, within year, would improve the situation and reduce potential sources age related error. As the stock is in a period of range expansion it is important that length at age is monitored with the most up to date information.

Horse mackerel were found distributed along the Irish west coast, Porcupine Bank and Celtic Sea. Geographical distribution was comparable to previous surveys but acoustic density of aggregations was lower than in 2019. Total stock biomass was 40% lower and total abundance was 21% lower compared to 2019 given comparable survey effort. The age composition of the stock in 2020 was dominated by younger age classes (ranked as: 3, 4, 7 & 6 years respectively) contributing over 69.6% of the total stock biomass. Immature fish represented over 16.4% of total abundance (8.5% of biomass). The 2017-year class (3-year-old fish) dominated the standing stock biomass, representing 21.8% of TSB and 21.8% of TSN. Maturity analysis indicates that 100% of fish of 3 years and above are fully recruited to the spawning stock.

Aggregations of Celtic Sea herring were encountered during the survey in the western and southern feeding grounds around the Pistola and Labadie Banks respectively. Two winter ring fish dominated the total estimate, representing 63% of total biomass and over 67% of total abundance. Three winter ring fish ranked second contributing 25.2% of the total biomass and 22.8% of total abundance. Combined these two age classes represented over 88% of total biomass and over 90% of total abundance. The presence of these year classes is of great importance to this stock given the prolonged period of poor recruitment observed. Given the 2-wr fish will spawn in the coming 2020/2021 winter season and if successful, will help to rebuild the stock back to a healthy and viable state.

Maturity analysis of Celtic Sea herring samples indicated 48% of 2-wr fish were mature, rising to 96% of 3-wr fish. Maturity analysis indicated over 64% of the TSB was mature and 58% of TSN.

Estimates of Celtic Sea herring biomass are not comparable to the stock index survey carried out in October and should not be used for comparative purposes. That said, estimates of biomass reported during WESPAS are important in tracking the stock during the summer feeding phase and contribute to our knowledge of the stock.

There were much fewer mackerel marks recorded in the survey area compared to 2019, although mackerel were caught in a majority of hauls throughout the survey area at all depths.

4.2 Conclusions

- Malin Shelf herring biomass in the WESPAS survey area was ~2.5 times higher in 2020 compared to 2019 (SSB_{2020} = 177,000 t SSB_{2019} =69,000 t)
- The Malin Shelf herring TSB in 2020 was ~4.3 times higher than 2019, driven mainly by a large increase in immature herring (TSB_{2020} = 370,000 t TSB_{2019} =87,000 t)
- The CV on the survey for Malin Shelf herring was lower in 2020 (0.25) when compared with 2019 (0.37); the CV in 2020 is comparable to previous years in the time series
- Malin Shelf herring were distributed further south again in 2020, similar to 2019 with some adult herring again found south of 56°N. This is the third year in a row in recent years that herring were found in this area. For instance, there was very little herring distributed south of 56°N in both 2016 and 2017.
- The 2020 Malin Shelf herring survey estimate was dominated by 1-wr (24% TSB and 43% TSN) and 2-wr (32% TSB and 29% TSN). There were good signs of young immature Malin Shelf herring (1-wr and 2-wr fish) found in discrete areas in both 6.a.S and 6.a.N
- Boarfish distribution showed a similar pattern to previous years. The number of schools and acoustic density of schools were notably higher across all survey strata, with the exception of the Porcupine Bank higher for comparable survey effort and timing.
- The 2020 boarfish TSB (total stock biomass) and abundance (TSN) estimates were 399,872 t and 9,893,782,000 individuals (CV 0.34). This TSB estimate is over double that observed in 2019 and the increase was evident across all but one survey stratum.
- The 15+ year age classes dominate the 2020 estimate contributing over 33.3% of TSB and 16.6% of TSN. The 8-year-old (11.5% TSB and 8.9% TSN) and 9-year –old age classes (10.8% TSB and 7.3% of TSN) ranked second and third respectively. Combined, the 15+, 8 and 9-year age classes represent 55.6% of TSB and 32.8% of TSN.
- The contribution of immature boarfish to the 2020 estimate surpassed levels observed in 2019 and represent 10.5% of total biomass and 41.4 % of total abundance. The proportion of immature fish is driven by a period of successful spawning and pre-recruit year classes (2017, 2018, 2019).
- The southern Celtic Sea and northern Biscay region continues to be an important nursery area for boarfish during the recent successful spawning period (2017-2020).
- Horse mackerel distribution was similar to previous years. A comparable number of echotraces were observed but the acoustic density was lower and this is reflected in the standing stock estimate.
- Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 47,553 t and 264,314,000 individuals (CV 0.31).

- The Celtic Sea stratum contained the largest proportion of biomass observed (55.1% of TSB), followed by the west coast (33.4%) and southern Hebrides (11.4%).
- Overall, the composition of horse mackerel aggregations was considered to be of low density with no of medium and high density schools detected and biological samples were taken as part of mixed species catches.
- The 3-year-old fish (2017-year class) dominated this year’s survey estimate representing 21.8% of TSB and 34.8% of TSN (Table 9). The 4-year-old fish ranked second representing over 19.3% of TSB and 19.5% of TSN. Seven-year-old fish were ranked third contributing 17.3% to TSB and 13.3% to TSN. Combined these three age classes represented 58.3% of TSB and 67.6% of TSN.
- Aggregations of Celtic Sea herring were observed around traditional feeding areas off the southwest and south Celtic Sea coast.
- Two winter ring fish dominated the total estimate, representing 63% of TSB (67% of TSN). Three winter ring fish ranked second contributing 25.2% of TSB (22.8% of TSN). Combined these two immature ages classes represented over 88% of total biomass and over 90% of total abundance.
- The 2-wr will fully recruit to the SSB this year and along with the 3-wr fish have the potential to bolster the stock given a successful spawning season this coming winter.
- The period 2017-2020 appears to have been an important period for spawning of small pelagic species monitored during WESPAS, with increased spawning success and the appearance of new and strong year classes.
- Due to the Covid pandemic additional work programs were curtailed in 2020 as was the PELGAS survey. The PELGAS survey provides important information of the southern boundary distribution of boarfish in the northern Biscay region as a result of survey overlap.
- Real time aging of horse mackerel is required to improve the tracking of age cohorts during the survey and improve the quality of the index. The boarfish age-length-key used to determine the age structure of the stock requires updating with new samples. Given the changes in distribution of the stock and pulses of strong recruitment it is important to track changes in growth rate to accurately track this dynamic stock.
- Containment gaps still exist for horse mackerel and boarfish in the western approaches to the English Channel. Extra ship days would be required to ensure better containment in this important area.
- To further develop this survey more ship-time is required. As the survey is observing not only target species for the focal component but also the distribution of other species that are also surveyed during the year, specifically Celtic Sea herring.

- Westward extension of some transects in the northwest of the survey area to ensure boarfish stock containment. This may also require some extra survey days.

5 Acknowledgements

We would like to thank Captains Denis Rowan and Anthony Hobin and the crew of the *Celtic Explorer* for their help and professionalism during the survey. Many thanks also to the seabird and marine mammal survey teams, who worked tirelessly during the survey in all weathers and with great enthusiasm.

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7 Tables and Figures

Table 1. Calibration report: Simrad EK60 echosounder at 38 kHz.

Echo Sounder System Calibration

Vessel : R/V Celtic Explorer		Date : 02.06.2020	
Echo sounder : EK60 PC		Locality : Dunmanus Bay	
Type of Sphere : WC-38,1	TS Sphere: -42.40 dB (Corrected for Soun vel)	Depth(btm) : 32 m	

Calibration Version 2.1.0.12

Comments:
WESPAS 2020_L1 Dunmanus Bay- WC38.1mm

Reference Target:

TS	-42.40 dB	Min. Distance	15.00 m
TS Deviation	5.0 dB	Max. Distance	22.00 m

Transducer: ES38B Serial No. 30227

Frequency	38000 Hz	Beamtype	Split
Gain	25.58 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	6.96 deg	Along. Beam Angle	6.93 deg
Athw. Offset Angle	-0.06 deg	Along. Offset Angl	-0.06 deg
SaCorrection	-0.69 dB	Depth	8.80 m

Transceiver: GPT 38 kHz 009072033933 2-1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.193 m
Power	2000 W	Receiver Bandwidth	2.43 kHz

Sounder Type:
EK60 Version 2.4.3

TS Detection:

Min. Value	-50.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %

Environment:

Absorption Coeff.	9.1 dB/km	Sound Velocity	1507.8 m/s

Beam Model results:

Transducer Gain =	25.69 dB	SaCorrection =	-0.67 dB
Athw. Beam Angle =	6.92 deg	Along. Beam Angle =	6.88 deg
Athw. Offset Angle =	-0.01 deg	Along. Offset Angle=	-0.03 deg

Data deviation from beam model:
RMS = 0.16 dB
Max = 0.59 dB No. = 245 Athw. = 4.0 deg Along = 2.6 deg
Min = -0.67 dB No. = 340 Athw. = -3.9 deg Along = 2.9 deg

Data deviation from polynomial model:
RMS = 0.15 dB
Max = 0.54 dB No. = 337 Athw. = -3.2 deg Along = 1.7 deg
Min = -0.67 dB No. = 154 Athw. = -3.0 deg Along = -3.3 deg

Comments :
Dunmanus Bay
Wind Force : 5 kn **Wind Direction :** SE
Raw Data File: E:\CE20008_WESPAS2020\Calibration\38 kHz Cal\WESPAS2020-D20190705-T090459.raw
Calibration File: E:\CE2008_WESPAS2020\Calibration\38 kHz Cal\Cal 38 kHz.txt

Calibration: Ciaran O'Donnell

Table 2. Catch table from directed trawl hauls.

No.	Date	Lat. N	Lon. W	Time	Bottom (m)	Target btm (m)	Bulk Catch (Kg)	Boarfish %	Mackerel %	Herring %	H Mack %	Others^ %
1	06-Jun	48.27	-7.50	09:34	176	126	45	97.0	3.0			
2	06-Jun	48.28	-6.81	14:21	155	117.5	4,000	99.5	0.5			
3	06-Jun	48.28	-6.09	18:20	130	15	20	68.6	5.9			25.5
4	08-Jun	48.76	-9.68	07:04	172	172	1,000	91.1			8.9	
5	08-Jun	48.76	-8.58	13:47	148	30	48	35.5	39.0		24.0	1.5
6	09-Jun	49.02	-10.61	17:42	140	110	1,000	90.0	4.0		6.0	
7	10-Jun	49.27	-10.00	10:00	145	133	250	41.0	47.6		1.6	9.8
8	10-Jun	49.27	9.03	16:17	135	30	1,000	100.0				
9	12-Jun	49.76	-8.81	15:39	101	40	1,500	92.6	6.2		0.4	0.8
10	13-Jun	50.01	-9.60	10:58	147	147	54		4.9	1.6	0.7	92.8
11	13-Jun	50.01	-10.94	18:23	180	40	30		76.4		18.3	5.3
12	14-Jun	50.26	-7.96	16:24	110	2.5	138			94.5		5.5
13	15-Jun	50.51	-9.29	07:56	125	100	5,000			99.9		0.1
14	15-Jun	50.51	-10.41	14:00	155	0	23		90.8		9.3	
15	16-Jun	50.76	-8.16	09:46	115	0	219		2.3	17.6		80.1
16	19-Jun	51.77	-11.06	13:05	164	80	5,000	99.9			0.1	
17	21-Jun	53.02	-11.56	19:32	148	7.5	0					
18	23-Jun	53.52	-10.75	05:36	125	100	2,000				0.6	99.4
19	25-Jun	53.53	-13.25	10:48	192	180	1,000					100.0
20	26-Jun	53.77	-10.70	10:36	150	130	14	1.0	1.0			98.0
21	26-Jun	54.01	-11.15	19:04	235	80	1,500	100.0				
22	29-Jun	55.02	-9.77	23:43	123	105	17	26.0	36.3	9.9	5.5	22.3
23	30-Jun	55.38	-8.06	21:54	70	50	500		12.7	86.9		0.4
24	01-Jul	55.45	-7.48	07:49	50	25	12		100.0			
25	01-Jul	55.55	-8.50	14:35	90	80	66		26.6	68.8		4.6
26	02-Jul	55.73	-8.41	06:13	108	95	200		11.1	88.2		0.8
27	02-Jul	55.90	-7.08	16:15	60	50	3,000		3.7	96.3		
28	03-Jul	56.07	-8.99	08:58	156	150	300	3.68	2.0	70.9	3.5	19.9
29	04-Jul	56.59	-7.51	16:58	186	125	2,000					100.0
30	05-Jul	56.84	-9.02	05:12	140	120	3,000	100.0				
31	06-Jul	57.59	-8.46	15:21	156	140	1,000			100.0		
32	08-Jul	58.35	-8.08	07:17	145	135	300		8.6	90.8		0.6
33	08-Jul	58.62	-7.95	14:22	240	50	0					
34	08-Jul	58.61	-7.03	19:34	91	75	117		7.3	92.2		0.5
35	09-Jul	58.60	-5.60	05:56	117	50	210					100.0

^ Includes non target pelagic and demersal fish species

Table 3. Malin Shelf herring stock estimate 2020 (6.a.S, 7.b,c and 6.a.N (south of 58°30’N).

	Age (years)													Numbers	Biomass	Mn Wt	Mature
Length	0	1	2	3	4	5	6	7	8	9	10	11	12+	(*10-3)	(t)	(g)	(%)
5.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
6		-	-	-	-	-	-	-	-	-	-	-	-	0			0
6.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
7		-	-	-	-	-	-	-	-	-	-	-	-	0			0
7.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
8		-	-	-	-	-	-	-	-	-	-	-	-	0			0
8.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
9		-	-	-	-	-	-	-	-	-	-	-	-	0			0
9.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
10		-	-	-	-	-	-	-	-	-	-	-	-	0			0
10.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
11		-	-	-	-	-	-	-	-	-	-	-	-	0			0
11.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
12		-	-	-	-	-	-	-	-	-	-	-	-	0			0
12.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
13		-	-	-	-	-	-	-	-	-	-	-	-	0			0
13.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
14		-	-	-	-	-	-	-	-	-	-	-	-	0			0
14.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
15		-	-	-	-	-	-	-	-	-	-	-	-	0			0
15.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
16		8055	-	-	-	-	-	-	-	-	-	-	-	8055	249.7	31	0
16.5		24165	-	-	-	-	-	-	-	-	-	-	-	24165	797.4	33	0
17		78302	-	-	-	-	-	-	-	-	-	-	-	78302	3121.5	39.86	0
17.5		157446	-	-	-	-	-	-	-	-	-	-	-	157446	6621.9	42.06	0
18		214173	-	-	-	-	-	-	-	-	-	-	-	214173	9877.6	46.12	0
18.5		218656	-	-	-	-	-	-	-	-	-	-	-	218656	11233.3	51.37	0
19		186070	-	-	-	-	-	-	-	-	-	-	-	186070	10424.5	56.02	0
19.5		218424	-	-	-	-	-	-	-	-	-	-	-	218424	13673	62.6	0
20		196501	-	-	-	-	-	-	-	-	-	-	-	196501	13557.1	68.99	0
20.5		146632	7344	-	-	-	-	-	-	-	-	-	-	153976	11819.3	76.76	0
21		71785	55147	-	-	-	-	-	-	-	-	-	-	126932	10472.7	82.51	0
21.5		13944	58615	-	-	-	-	-	-	-	-	-	-	72559	6364.1	87.71	0
22		7581	117152	-	-	-	-	-	-	-	-	-	-	124733	11901.2	95.41	12.1556
22.5		-	134626	-	-	-	-	-	-	-	-	-	-	134626	13557.4	100.7	9.74775
23		-	199027	35018	-	-	-	-	-	-	-	-	-	234045	25471.3	108.83	34.5122
23.5		-	159386	41300	-	-	-	-	-	-	-	-	-	200686	23078.2	115	23.3738
24		-	128999	101979	646	-	-	-	-	-	-	-	-	231624	28907.1	124.8	60.4285
24.5		-	107743	82132	16135	-	-	-	-	-	-	-	-	206010	27517.2	133.57	56.1089
25		-	62229	95467	16268	3308	-	-	-	-	-	-	-	177272	25142.7	141.83	68.8981
25.5		-	15264	75677	40566	-	-	-	-	-	-	-	-	131507	19763.1	150.28	89.4006
26		-	11193	38321	41014	19012	17848	-	-	-	-	-	-	127388	20224.2	158.76	76.8817
26.5		-	2489	24966	35097	9157	13122	498	-	-	-	-	-	85329	14608.9	171.21	95.9158
27		-	-	8876	30004	15677	24755	2744	941	-	-	-	-	82997	14961.6	180.27	99.9988
27.5		-	-	3104	10308	20890	25016	6626	947	-	-	-	-	66891	12633.1	188.86	100
28		-	-	-	1073	3667	42482	2851	2507	2014	-	-	-	54594	11154.5	204.31	100.002
28.5		-	-	-	-	8759	21411	7808	2751	-	-	-	-	40729	8626.4	211.8	99.9975
29		-	-	-	-	2342	19910	5270	5856	-	-	-	-	33378	7579.7	227.09	100
29.5		-	-	-	-	-	11364	6579	-	-	-	-	-	17943	4106.7	228.87	100.006
30		-	-	-	-	-	-	-	1456	7282		-	-	8738	2086.2	238.75	100
30.5		-	-	-	-	-	-	-	1209	-	-	-	-	1209	275.7	228	100
31		-	-	-	-	-	-	-	-	-	-	-	-	0			0
32.5		-	-	-	-	-	-	837	-	-	-	-	-	837	240.9	288	100
TSN (1000)	0	1541734	1059214	506840	191111	82812	175908	33213	15667	9296				3615795			
TSB (t)		88711.9	118413	70201.7	30855.4	14777.2	34631.3	7002.7	3298.3	2157.3					370048.2		
Mean length (cm)		18.95	23.16	24.73	26.02	27.02	27.74	28.48	28.75	29.57							
Mean weight (g)		57.54	111.79	138.51	161.45	178.44	196.87	210.84	210.53	232.06						102.34	
SSB (t)		0	37375.4	47396.1	30855.4	14777.2	34631.3	7002.7	3298.3	2157					177493.4		
% mature		0	28	65	100	100	100	100	100	100							

Table 4. Malin Shelf herring survey time series 2008-2020. Survey coverage: - ^ 6.a.S & 7.b,c; * 6.a.S, 6.a.N & 7.b; ** 6.a & 7.b,c; ***6.a.S, 7.b,c & 6.a.N (south of 58°30’N).

Age	2008^	2009^	2010*	2011*	2012*	2013*	2014*	2015**	2016*	2017***	2018***	2019***	2020***
0	-	-	-	-	-	-	-	-	-	-	264.6		
1	6.1	416.4	524.8	82.1	608.3	-	1,115.4	4.9	-	-	395.8	21.6	1541.7
2	75.9	81.3	504.3	202.5	451.5	96.2	214.7	162.1	9.7	11.0	339.2	212.4	1059.2
3	64.7	11.4	133.3	752.0	444.6	254.3	166.3	291.7	102.3	273.4	112.5	174.5	506.8
4	38.4	15.1	107.4	381.0	516.1	265.8	380.0	580.7	91.4	111.0	314.1	86.3	191.1
5	22.3	7.7	103.0	110.8	180.3	78.7	352.1	487.3	91.4	71.6	137.5	55.3	82.8
6	26.2	7.1	83.7	124.0	115.4	26.9	125.0	513.4	58.2	94.4	43.7	29.1	175.9
7	9.1	7.5	57.6	118.4	116.9	18.5	18.9	143.9	46.5	28.0	59.5	3.4	33.2
8	5.0	0.4	35.3	70.7	83.8	10.8	9.7	33.4	2.7	9.9	16.8	11.7	15.7
9	3.7	0.9	17.5	41.6	56.3	4.1	4.7	-	0.5	2.6	8.2	3.8	9.3
10+	-	-	-	25.6	42.0	1.2	-	8.3	-	-	6.4		
TSN (mil)	251.4	547.7	1,566.9	1,908.7	2,615.0	756.6	2,386.8	2,225.5	402.8	601.8	1,698.3	598.0	3,615.8
TSB (t)	44,611.0	46,460.0	192,979.0	313,305.0	397,797.0	118,946.0	294,200.0	449,343.0	70,745.0	107,900.0	183,187.5	86,641.1	370,048.2
SSB (t)	43,006.0	20,906.0	170,154.0	284,632.0	325,835.0	92,700.0	200,200.0	425,392.0	69,269.5	106,657.0	129,740.0	68,607.0	177,493.7
CV	34.2	32.2	24.7	22.4	22.8	21.5	28.6	28.6	31.3	46.6	28.3	37.3	24.9

Table 5. Malin Shelf herring SSB and SSN by strata in the WESPAS survey area 2020.

Strata	Name	Area (nmi^2)	Transects	SSN ('000)	SSB (t)
1	Minches	3604	7	5,203	627
2	W Hebrides	7100	7	500,232	88,918
3	SW Hebrides	4867	4	251,899	35,556
4	NW Coast	2257	2	32,664	4,304
5	W Coast	11232	12	42,962	6,038
6	N Malin	3102	3	305,367	42,050
	Total	32,162	35	1,138,327	177,493

Table 6. Total boarfish stock estimate.

Length	Age (years)																Numbers	Biomass	Mn Wt	Mature
(cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Unknown	(000's)	(t)	(g)	(%)
4																	6144				
4.5	52797																	52797	105.6	2	0
5	349161																	349161	1138.6	3	0
5.5	681953																	681953	2675.1	4	0
6		458987																458987	2262.4	5	0
6.5		108865																108865	681.8	6	0
7		71962																71962	585.6	8	0
7.5		256716	71584															328300	3232.2	10	0
8			642667															642667	7671.9	12	0
8.5			370676	219836														590511	8382	14	0
9			71730	346353														418083	7260.1	17	0
9.5				327187														327187	6529.8	20	0
10				73132														73132	1678.6	23	80
10.5					40469													40469	1037.3	26	100
11					72133													72133	2185.9	30	100
11.5						63103	89254											152357	5068.5	33	100
12						94188	94018	198906										387112	14676.6	38	100
12.5								339927	126926									466853	20608.2	44	100
13								67521	367495	90311								525327	26059.2	50	100
13.5								287807	213875	185129	41256							728067	40972.5	56	100
14								18713	176197	445297	231986	11006		14555		20793		918547	56900.6	62	100
14.5											39215	67377	132926	230977	150886	237386		858766	57911.9	67	100
15											18469	2230	57337	40172	112255	533758		764221	58225.5	76	100
15.5													4596	12952	3566	520376		541489	44011.8	81	100
16																223144		223144	19847.3	89	100
16.5																74221		74221	7190.5	97	100
17																31326		31326	2960.5	95	100
17.5																					
18																					
18.5																					
19																					
19.5																					
TSN (10^{-3})	1083910	896531	1156657	966507	112602	157291	183273	912874	884493	720737	330926	80613	194859	298655	266707	1641003	6144	9893782			
TSB (t)	3919.3	5965.8	14608.9	17709.7	3223.2	5333.5	6552.3	42293.1	46169.4	43003.4	21293.4	5085.4	12768.7	20206.3	18768.2	132959.4	12.3		399872		
Mean length (cm)	5.29	6.57	8.19	9.13	10.82	11.8	11.76	12.77	13.25	13.75	14.05	14.45	14.67	14.59	14.72	15.32	4				
Mean weight (g)	3.62	6.65	12.63	18.32	28.62	33.91	35.75	46.33	52.2	59.67	64.34	63.08	65.53	67.66	70.37	81.02	2			40.42	
% mature*	0	0	0	1	100	100	100	100	100	100	100	100	100	100	100	100	0				
SSB	0.0	0.0	112.1	387.1	2938.4	5333.5	6552.3	42293.1	46169.4	43003.4	21293.4	5085.4	12768.7	20206.3	18768.2	132959.4	0.0		357871		

Table 7. Boarfish biomass and abundance by strata.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
W Hebrides	3,253.6	6	258,020	16,304
S Hebrides	2,108.8	5	355,708	21,037
W Coast	13,565.5	21	1,733,681	87,406
Porcupine Bank	4,627.3	6	178,565	12,787
Celtic Sea	27,934.2	15	7,366,808	262,339
Total	51,4891	53	9,893,782	399,872.1

Table 8. Boarfish survey time series.

Age (Yrs)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0	-	-	-	-	-	-	-	-	-	1083.9
1	5.0	21.5	-	-	198.5	4.6	110.9	76.7	782.3	896.5
2	11.6	10.8	78.0	-	319.2	35.7	126.7	31.2	389.1	1156.7
3	57.8	174.1	1,842.9	15.0	16.6	45.5	344.6	115	96.8	966.5
4	187.4	64.8	696.4	98.2	34.3	43.6	367.3	68.3	93.1	112.6
5	436.7	95.0	381.6	102.3	80.0	6.0	156.0	106.7	88.2	157.3
6	1,165.9	736.1	253.8	104.9	112.0	10.0	209.0	165.9	105.9	183.3
7	1,184.2	973.8	1,056.6	414.6	437.4	169.0	493.1	320.7	445.7	912.9
8	703.6	758.9	879.4	343.8	362.9	112.6	468.3	197.7	182.6	884.5
9	1,094.5	848.6	800.9	341.9	353.5	117.6	397.2	293.4	288	720.7
10	1,031.5	955.9	703.8	332.3	360.0	96.6	285.8	624.7	290.1	330.9
11	332.9	650.9	263.7	129.9	131.7	17.0	120.9	339.2	49.5	80.6
12	653.3	1,099.7	202.9	104.9	113.0	32.0	82.1	264.1	192.2	194.9
13	336.0	857.2	296.6	166.4	174.0	48.7	74.4	198.4	79.1	298.7
14	385.0	655.8	169.8	88.5	108.0	18.3	220.4	116.5	57.2	266.7
15+	3,519.0	6,353.7	1,464.3	855.1	1,195.0	400.1	931.0	302.4	758.9	1641.0
TSN (10^{-3})	11,104	14,257	9,091	3,098	3,996	1,157	4,387	3,221	3,899	9,888
TSB (t)	670,176	863,446	439,890	187,779	232,634	69,690	223,860	186,252	179,156	399,872
SSB (t)	669,392	861,544	423,158	187,654	226,659	69,103	218,810	184,235	169,216	357,871
CV	21.2	10.6	17.5	15.1	17.0	16.4	21.9	19.9	25.4	34.8

Table 9. Horse mackerel stock estimate.

Length	Age (years)																					Numbers	Biomass	Mn Wt	Mature
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21 Unknown	(000's)	(t)	(g)	(%)
11																									
12																									
13																									
14																									
15																									
16																									
17																									
18		6168																				6168	308.4	50	0
19																									
20																									
21			18505																			18505	1665.4	90	100
22			36600																			36600	3695.8	101	100
23			11837																			11837	1430.9	121	100
24			10852	3954																		14805	1918.1	130	100
25			3756	2879																		6635	978.1	147	100
26			9864	10955																		20819	3485.5	167	100
27			511	18672	8484	14395	511															42574	7724.4	181	100
28				12131	12947	1573	3145															29795	6037	203	100
29				2947	1587	8479	11494	907														25413	5375.1	212	100
30					1267	2535	11829	1267														16899	4053.8	240	100
31							2407	1532	1750													5689	1465.1	258	100
32							4692	1005	1005					670								7373	2073.8	281	100
33							1021	510	2552					1021								5104	1570.6	307.7	100
34									7761	1455	485			1940								11642	3906.4	335.54	100
35													565	565								1129	425.3	376.5	100
36																809						809	305.9	378	100
37														1258		1258						2517	1133.8	450.5	100
38																									
39																									
40																									
41																									
42																									
TSN (10^{-3})		6168	91924	51538	24285	26981	35099	5222	13069	1455	485		565	5455		2068						264314			
TSB (t)		308.4	10350	9178.2	4775.4	5365.8	8213	1416.9	4146.4	515.2	168.8		209.5	1998.3		907.4							47553.4		
Mean length (cm)		18	22.74	26.8	27.82	27.97	29.87	30.8	33.25	34	34		35	34.36		36.61									
Mean weight (g)		50	112.59	178.09	196.64	198.87	234	271.36	317.26	354	348		371	366.35		438.86								179.91	
% mature*		0	100	100	100	100	100	100	100	100	100		100	100		100									
SSB			6,629	9,178	4,775	5,366	8,213	1,417	4,146	515	169		210	1,998		907							43523.6		

Table 10. Horse mackerel biomass and abundance by strata.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
W Hebrides	5,648.8	6	0	0
S Hebrides	2,108.8	5	33,326	5,437.1
N Stanton	1,798.5	5	0	0
S Stanton	1,779.3	4	0	0
W Coast	14,735.3	21	123,366	15,898
Porc Bank	4,627.3	6	0	0
Celtic Sea	27,934.2	15	107,622	26,218
Total	58,632.1	62	264,314	47,553

Table 11. Horse mackerel survey time series.

Age (Yrs)	2016	2017	2018	2019	2020
0					
1	1.1	11.7	1.0	63.7	
2	100.2	181.8	72.4	14.3	6.2
3	4.9	147	243.3	9.2	91.9
4	43.5	45.4	85.3	46.4	51.5
5	19.0	16.2	10.5	30.9	24.3
6	7.6	46	7.6	18.5	27.0
7	40.6	113	49.3	29.8	35.1
8	66.6	67.7	13.3	6.2	5.2
9	8.5	25.4	10.0	26.7	13.1
10	1.8	33.2	1.5	0.4	1.5
11	9.5	32.6	1.5	1.9	0.5
12	10.6	37.7	7.4	3.9	
13	4.7	37.6	8.5	0.6	0.6
14	21.1	160.8	27.5	23.2	5.5
15	6.5	8.6		10.0	
16	1.6	5.2		28.4	2.1
17	5.3		0.3		
18				17.7	
19					
20					
21	1.1				
TSN (10^{-3})	354.5	969,655	540,422	333,501	264,314
TSB (t)	69,267	228,116	92,932	79,026	47553
SSB (t)	65,194	227,395.6	89,050	77,529	43,527
CV	42.0	25.5	36.8	33.7	31.2

Table 12. Celtic Sea herring stock estimate.

Length (cm)	Age (years) 1	2	3	4	5	6	7	8	9	10	11	Unknown	Numbers (10^{-3})	Biomass (t)	Mn Wt (g)	Mature (%)
11.5																
12																
12.5																
13																
13.5																
14																
14.5																
15																
15.5																
16																
16.5																
17																
17.5																
18																
18.5		579	1737										2316	254.8	110	0
19	4847	1212											6059	519.3	86	50
19.5		8375											8375	720.9	86	0
20	994	11932	2486	2983									18395	1994.6	108	75
20.5		32920	10793										43713	4176	96	50
21		61321	13448		1614								76382	7023.4	92	35
21.5	7848	41853	14823		3052								67576	6835.6	101.15	54
22		52239	12311	665	2329		1664						69209	7465.6	107.87	68
22.5		29120	11030	3309	1103	441		882					45886	5248.8	114.39	77
23	416	23929	16022	208	2913								43489	5038.1	115.85	77
23.5		15703	6137		902	722							23465	2563.6	109.25	71
24		9844	5548	1790	358								17540	1922.4	109.6	68
24.5		2940	3104	980	817								7841	973.2	124.12	85
25		3155	1735										4890	570.1	116.58	73
25.5			187	1248		250							1684	221.3	131.37	80
26			1577	1290	860								3728	481.8	129.23	100
26.5		388		106		35							529	62.5	118	100
27					1130								1130	174.1	154	100
27.5												48	48	7.7	160	100
28						729							729	111.8	153.25	100
28.5																
29																
29.5																
30																
30.5																
31																
31.5																
TSN (10^{-3})	14105	295512	100939	12579	15079	2177	1664	882				48	442986			
TSB (t)	1054.8	29184.2	11666	1632.5	2093.7	315	271.8	140.3				7.7		46365.5		
Mean length (cm)	20.58	21.72	22.14	22.95	22.9	25.08	22	22.5				28				
Mean weight (g)	74.78	98.76	115.57	129.77	138.85	144.68	163.4	159				160			104.67	
% mature*	0	48	96	100	100	100	100	100				100				
SSB (t)		14378.4	10971.7	1632.5	2093.7	315.0	271.8	140.3						29803.4		

Table 13. Celtic Sea herring total stock biomass and total abundance by strata.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
Celtic Sea	27,934.2	16	442,986	46,337
Total	27,934.2	16	442,986	46,337

Table 14. Marine mammal and megafauna sightings, counts and group size ranges for cetaceans sighted during the survey (includes on and off effort).

Sightings		**No. of sightings**	**No. of individuals**	**Group size**
Odontocetes	Common dolphin	68	1,922	2-250 (28)
	Bottlenose dolphin	15	259	3-40 (17)
	Harbour porpoise	7	10	1-3 (1)
	Long-finned pilot whale	2	55	15-40 (28)
	Risso's dolphin	5	25	3-10 (5)
	White-beaked dolphin	1	2	2
	Atlantic white-sided dolphin	4	48	3-15 (12)
	Unidentified dolphin	6	39	2-15 (7)
	Total odontocetes	*108*	*2,360*	*/*
Mysticetes	Fin whale	33	38	1-3 (1)
	Humpback whale	11	19	1-4 (2)
	Minke whale	57	61	1-3 (1)
	Unidentified whale	20	20	1
	Total mysticetes	*121*	*138*	*/*
Pinnipeds	Grey seal	6	7	1-2 (1)
Unidentified cetaceans		1	1	1
Total marine mammals		*236*	*2,506*	*/*
Other megafauna	Basking shark	1	1	1
	Blue shark	1	1	1
	Unidentified shark	1	1	1
	Sunfish	9	13	1-4 (1)
TOTAL		**248**	**2,522**	**/**

Table 15. Totals for all seabird and terrestrial bird species recorded.

Common Name	*Species name*	*No. of Sightings*	*No. of Seabirds*	*In Tran-sect*	*Off Transect*
Fulmar	*Fulmarus glacialis*	1344	14115	1901	12214
Sooty Shearwater	*Puffinus griseus*	15	23	13	10
Manx Shearwater	*Puffinus puffinus*	553	26098	12381	13717
Fea's type Petrel	*Pterodroma feae/ deserta*	1	1	1	0
Wilson's Petrel	*Oceanites oceanicus*	7	7	6	1
Storm Petrel	*Hydrobates pelagicus*	555	3628	1083	2545
Leach's Petrel	*Oceanodroma leucorhoa*	1	1	1	0
Gannet	*Morus bassanus*	2048	16681	3899	12782
Pomarine Skua	*Stercoratius pomarinus*	7	9	5	4
Arctic Skua	*Stercoratius parasiticus*	10	12	7	5
Long-tailed Skua	*Stercoratius longicaudus*	9	12	8	4
Great Skua	*Stercoratius skua*	144	240	91	149
Common Gull	*Larus canus*	1	1	1	0
Sabine's gull	*Larus sabini*	1	1	1	0
Black-headed Gull	*Larus ridibundus*	1	1	1	0
Lesser Black-backed Gull	*Larus fuscus*	192	1187	164	1023
Herring Gull	*Larus argentatus*	18	51	22	29
Yellow-legged gull	*Larus michahellis*	5	6	0	6
Great Black-backed Gull	*Larus marinus*	26	39	9	30
Kittiwake	*Rissa tridactyla*	152	1089	237	852
Common Tern	*Sterna hirundo*	9	22	15	7
Arctic Tern	*Sterna paradisaea*	9	14	10	4
Commic tern sp.	*Sterna hirundo / Sterna paradisaea*	2	17	17	0
Guillemot	*Uria aalge*	205	925	795	130
Razorbill	*Alea torda*	47	116	99	17
Razorbill / Guillemot	*Alea torda / Uria aalge*	1	60	60	0
Puffin	*Fratercula arctica*	382	876	631	245
Shag	*Phalacrocorax aristotelis*	4	9	9	0
Great Northern Diver	*Gavia immer*	1	1	1	0
	Total	**5750**	**65242**	**21468**	**43774**

Table 15 cont.

Common Name	*Species name*	*No. of Sightings*	*No. of Individuals*
Black Redstart	*Phoenicurus ochruros*	1	1
Black-tailed Godwit	*Limosa limosa*	1	46
Collared Dove	*Streptopelia decaocto*	2	2
Common Scoter	*Melanitta nigra*	1	14
Spotted Flycatcher	*Muscicapa striata*	1	1
Swallow	*Hirundo rustica*	2	2
Tufted Duck	*Aythya fuligula*	1	4
White-tailed Eagle	*Haliaeetus albicilla*	1	1
	Total	**10**	**71**

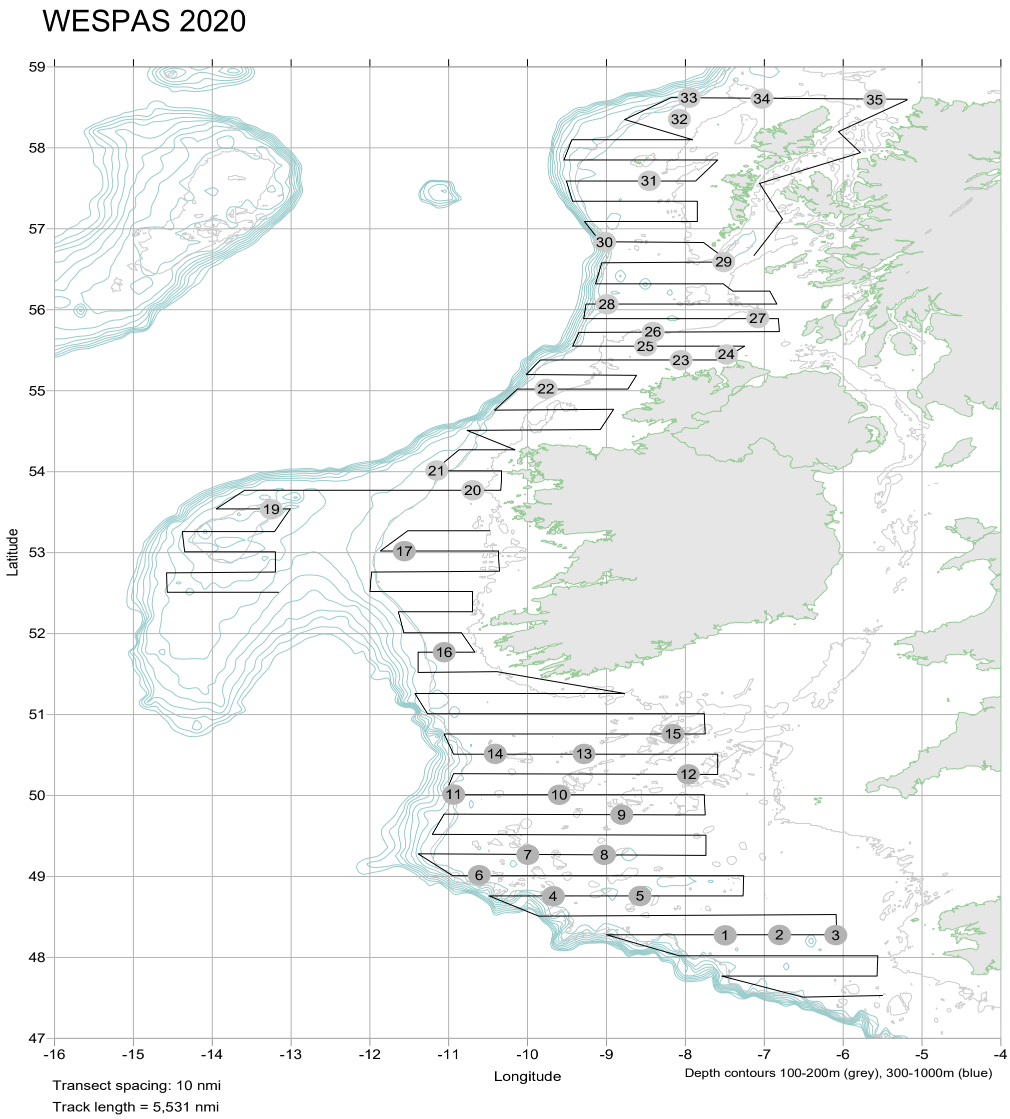


Figure 1. Survey cruise track (grey line) and numbered directed pelagic trawl stations. Corresponding catch details are provided in Table 2.

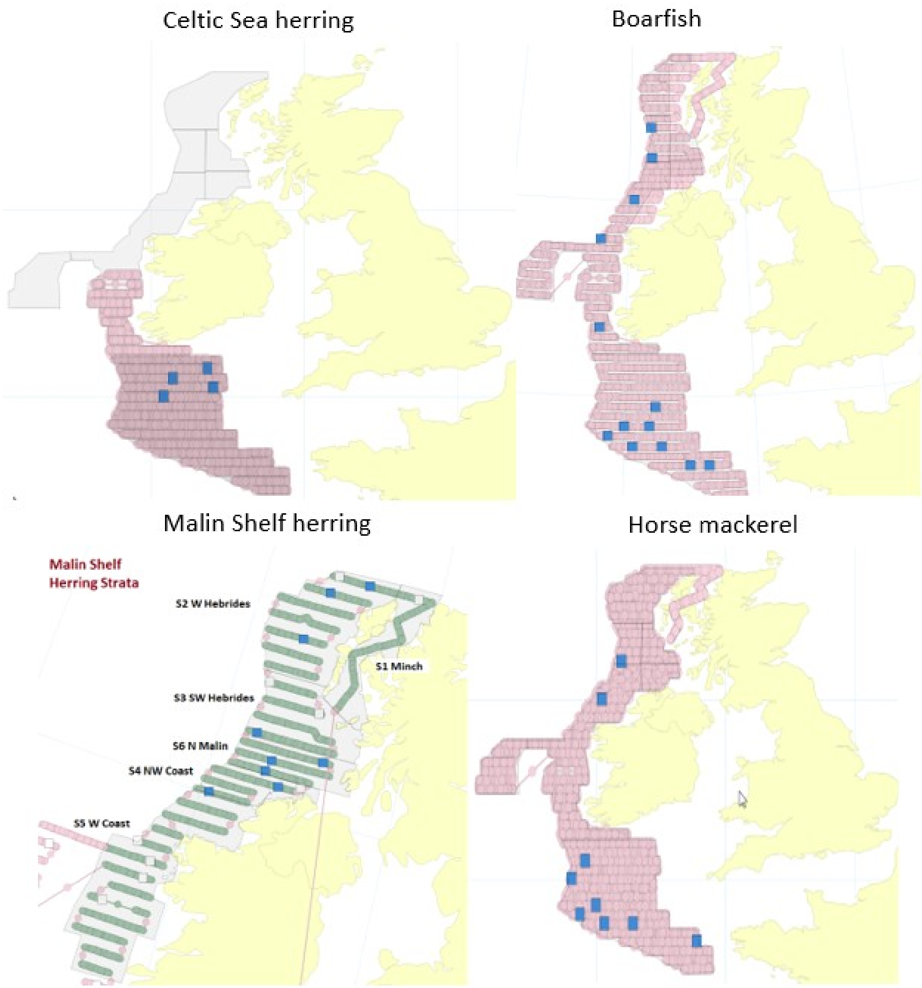


Figure 2. Species specific acoustic sampling stratification taken from StoX.

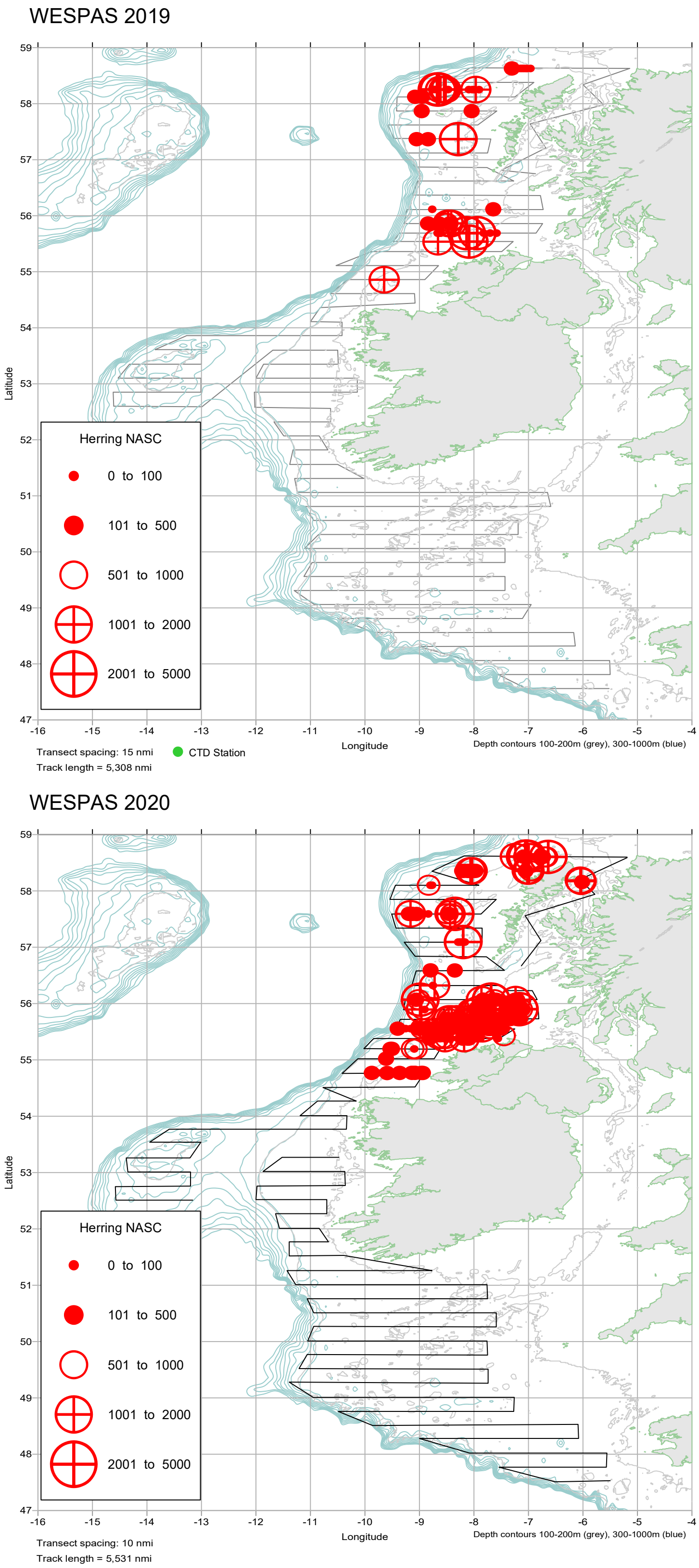


Figure 3. Malin Shelf (north of 54°N) herring distribution by weighted acoustic density. Top panel 2019, bottom panel 2020.

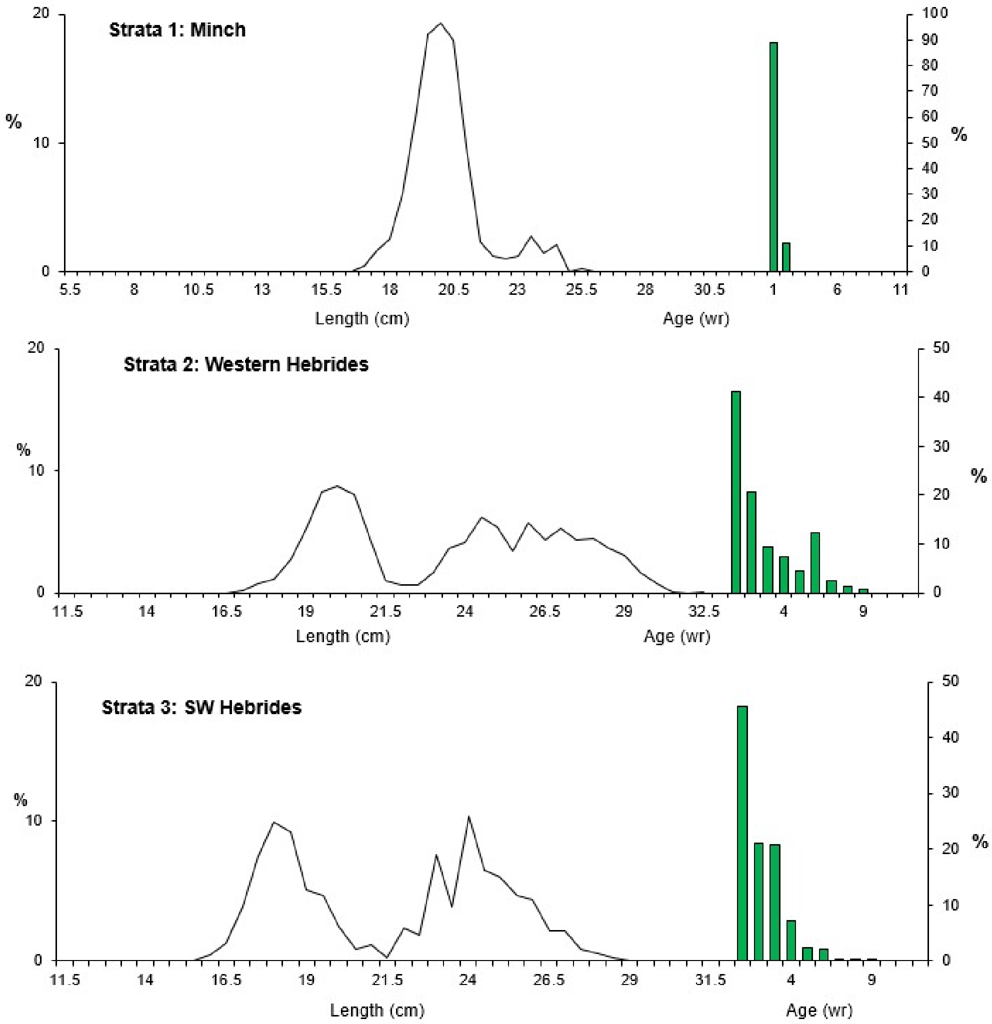


Figure 4. Length and age distribution of Malin Shelf herring by stratum and total survey area during WESPAS 2020.

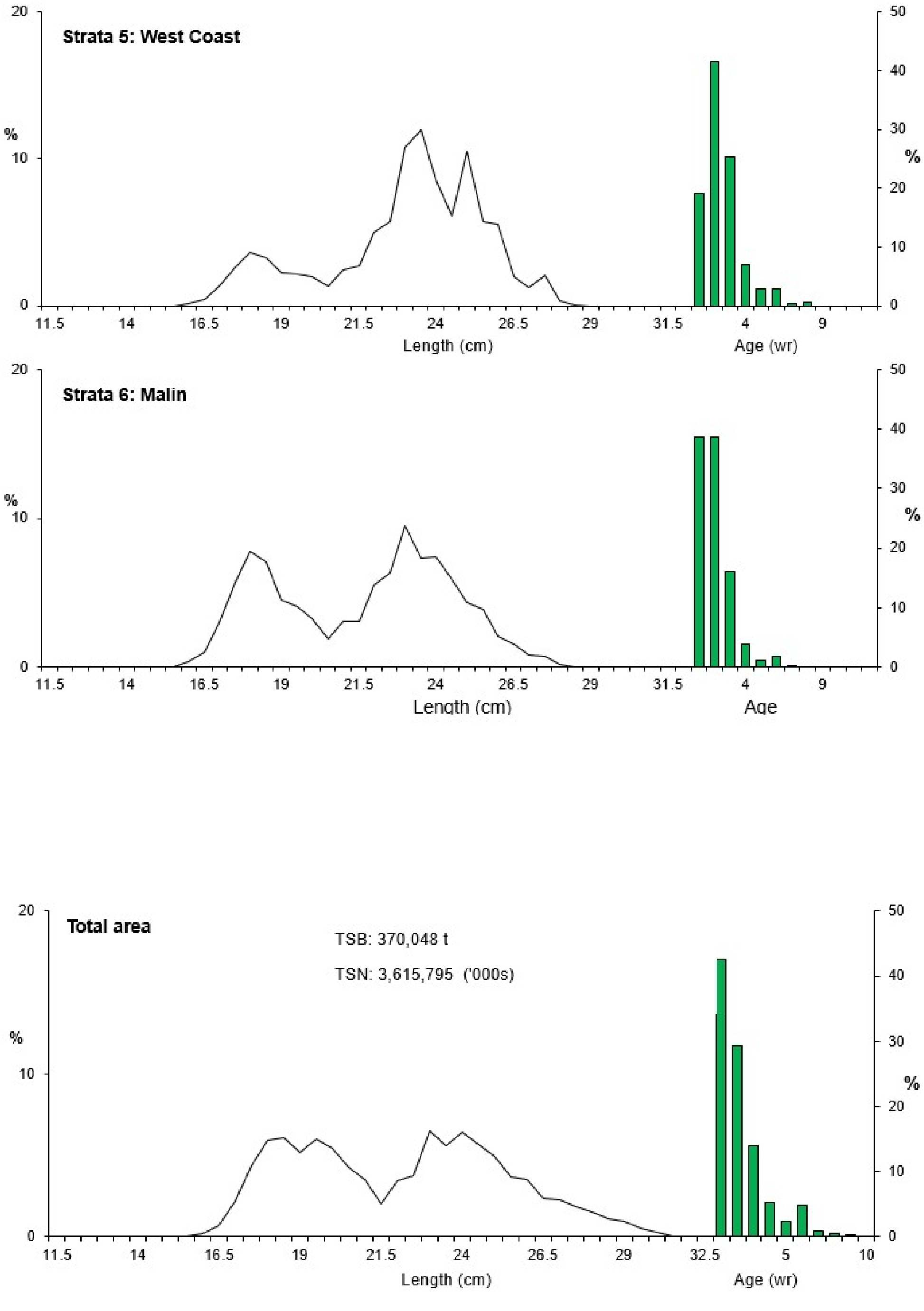
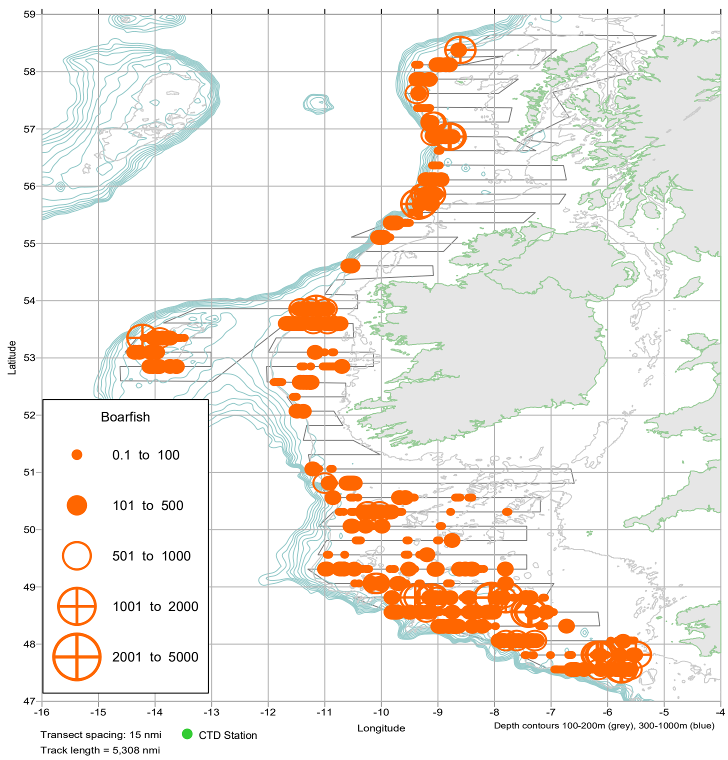


Figure 4. *Continued.* Length and age distribution of Malin Shelf herring by stratum and total survey area during WESPAS 2020.

WESPAS 2019



WESPAS 2020

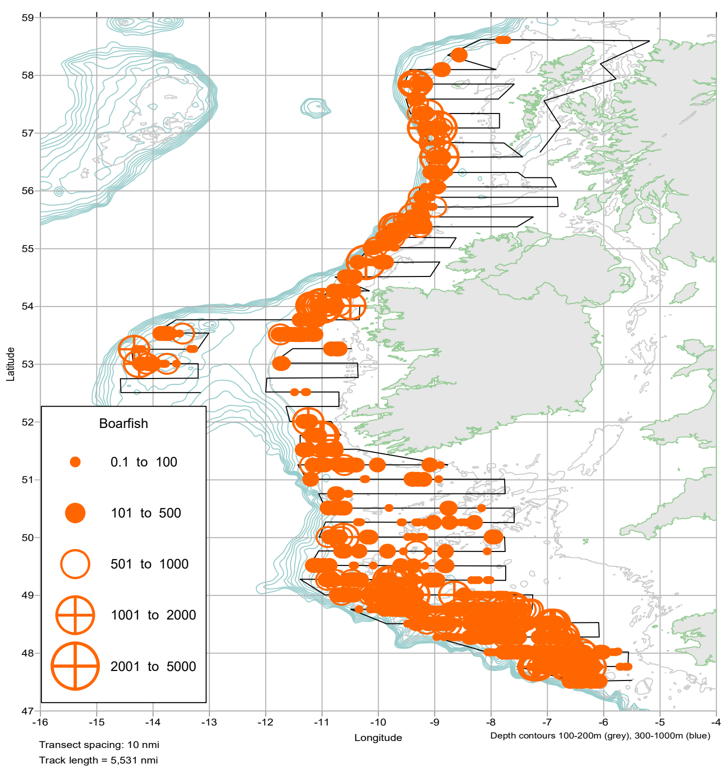


Figure 5. Boarfish distribution by weighted acoustic density. Top panel 2019, bottom panel 2020.

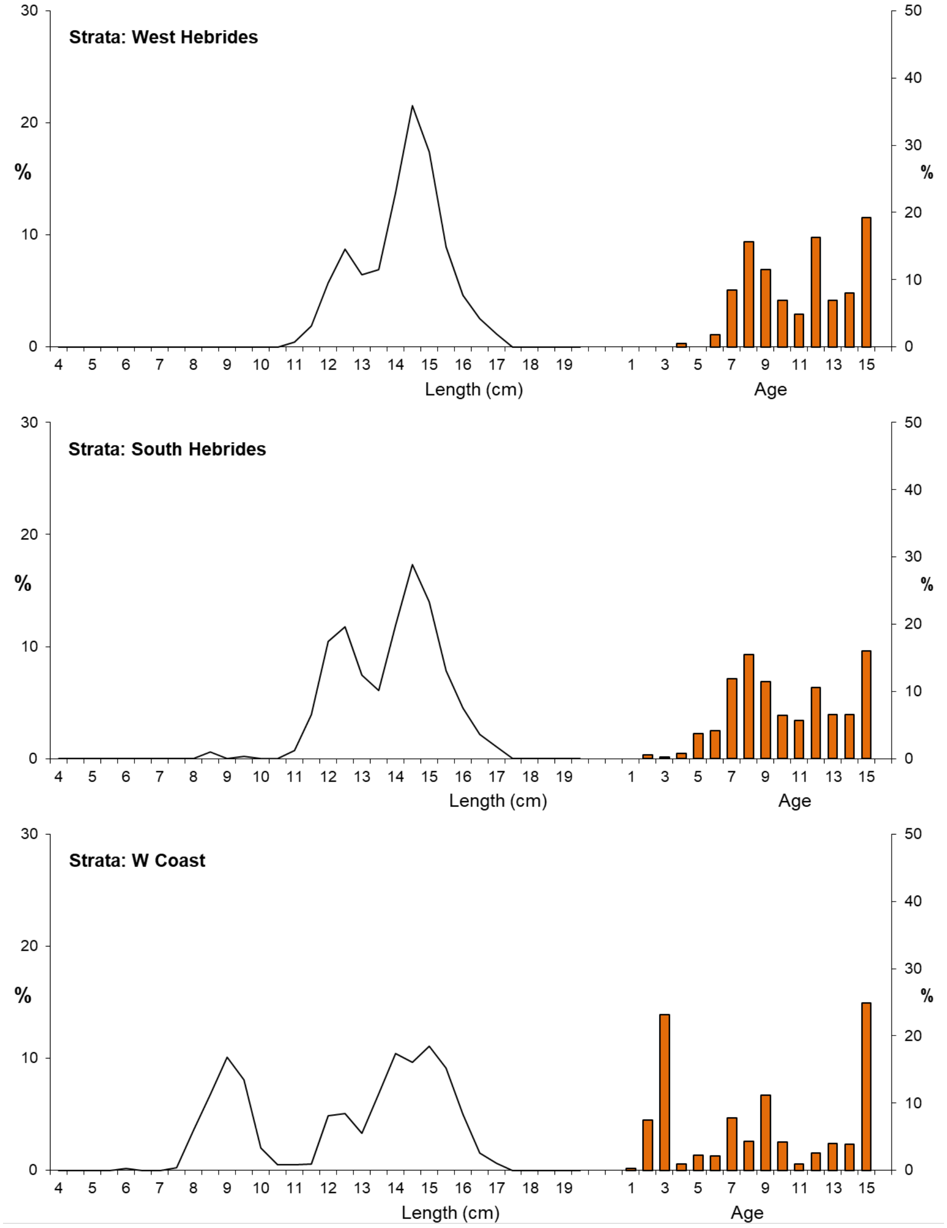


Figure 6. Abundance at length and age distribution of boarfish by stratum and total survey area.

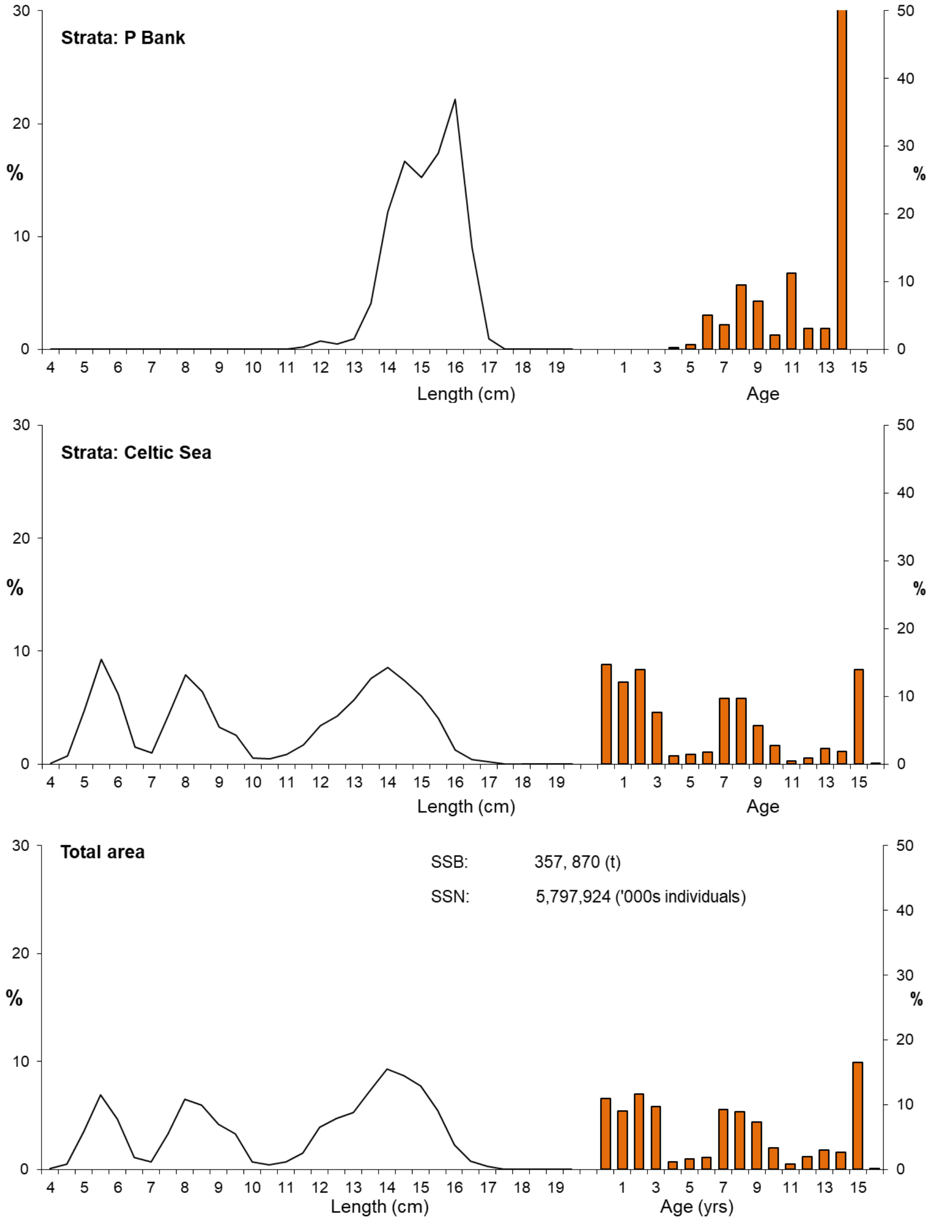


Figure 6. cont.

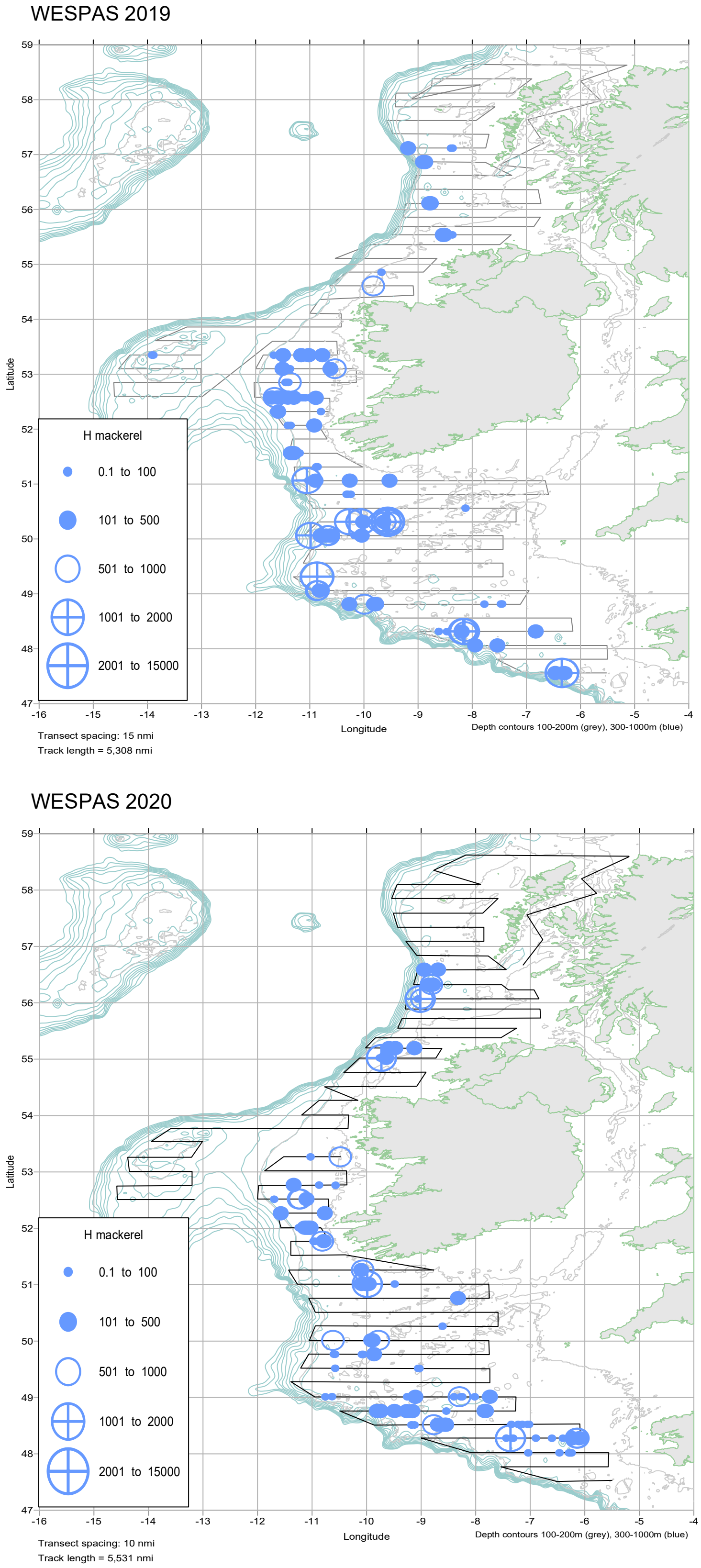


Figure 7. Horse mackerel distribution by weighted acoustic density. Top panel 2019, bottom panel 2020.

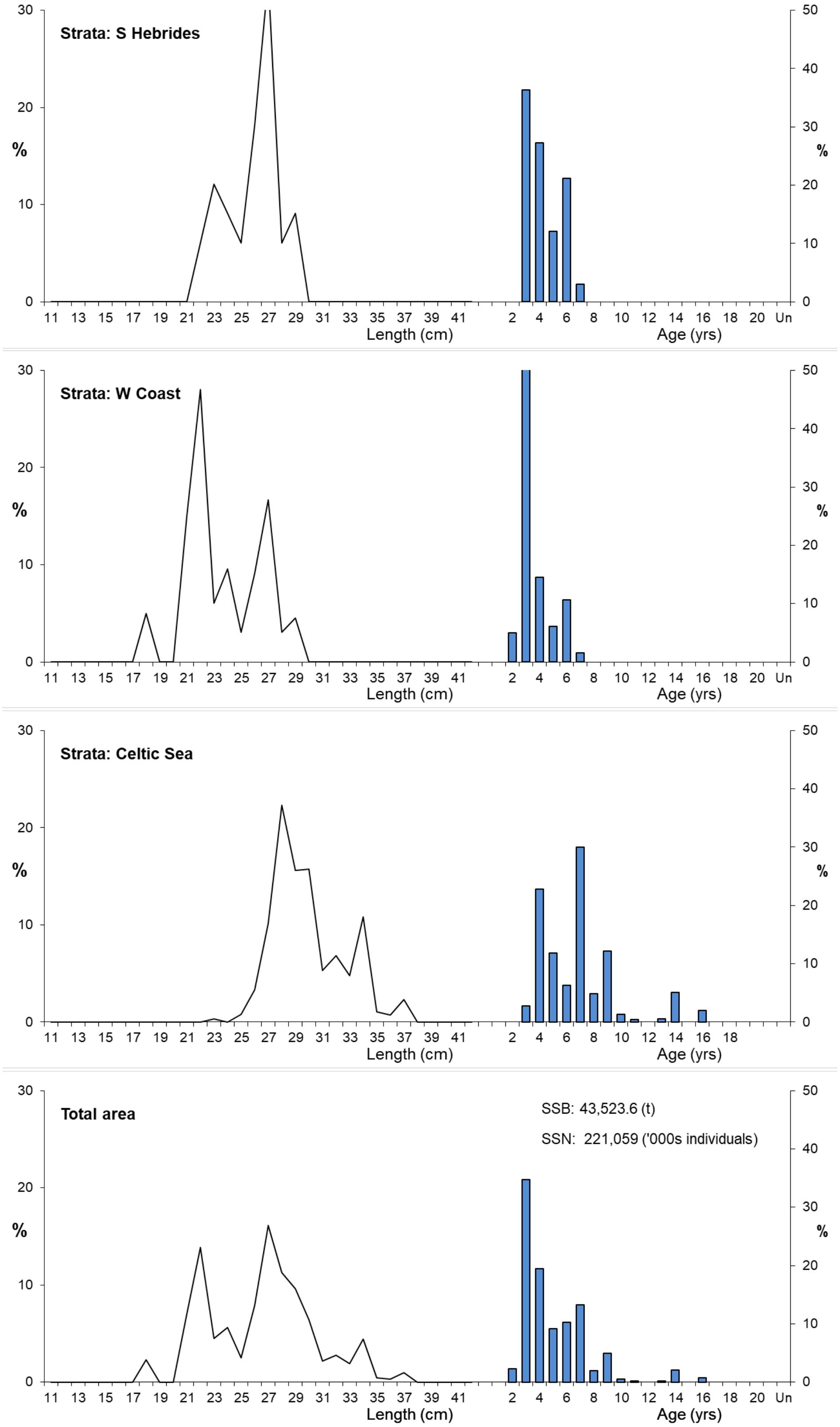


Figure 8. Length and age distribution of horse mackerel by stratum and total survey area.

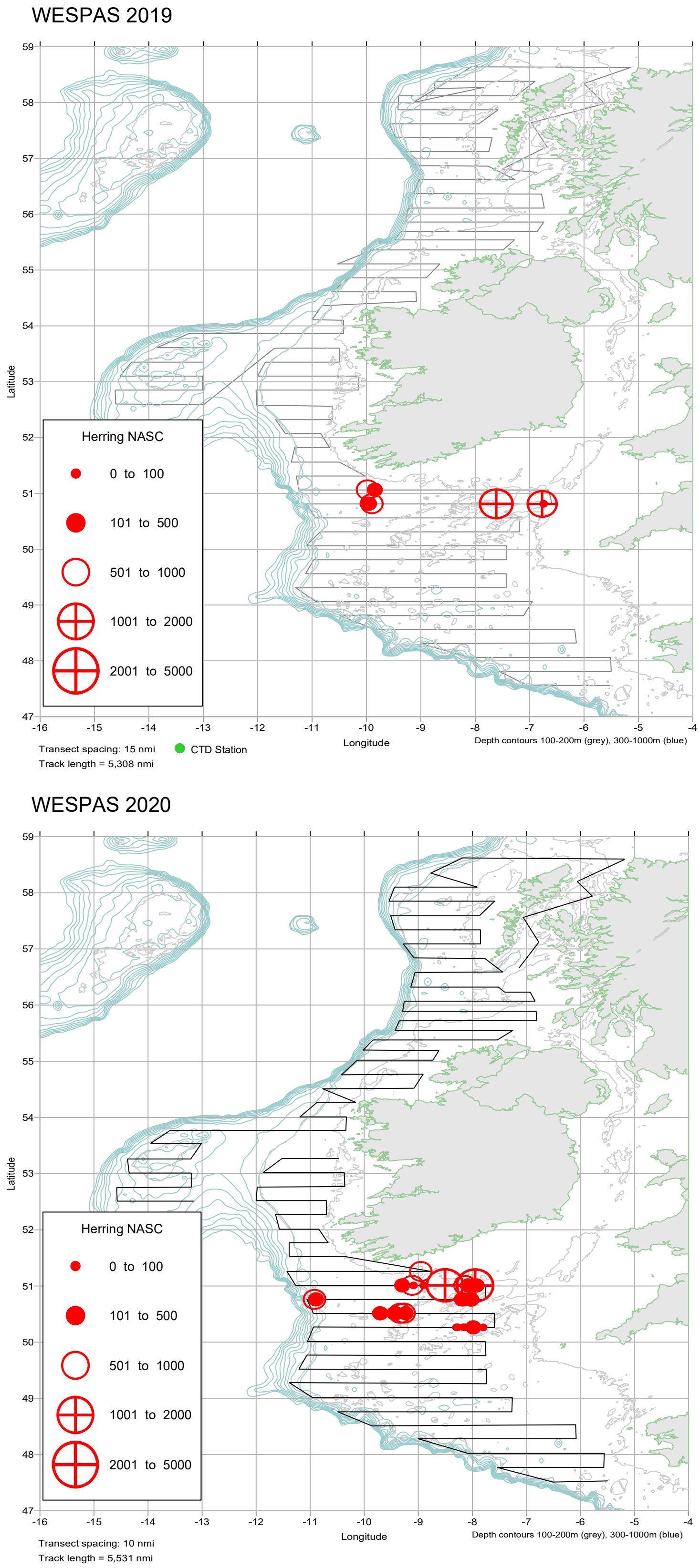


Figure 9. Celtic Sea herring distribution by weighted acoustic density. Top panel 2019, bottom panel 2020.

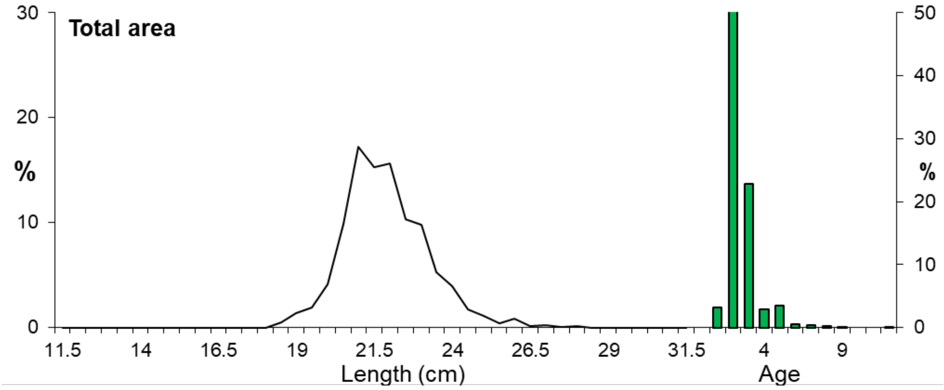
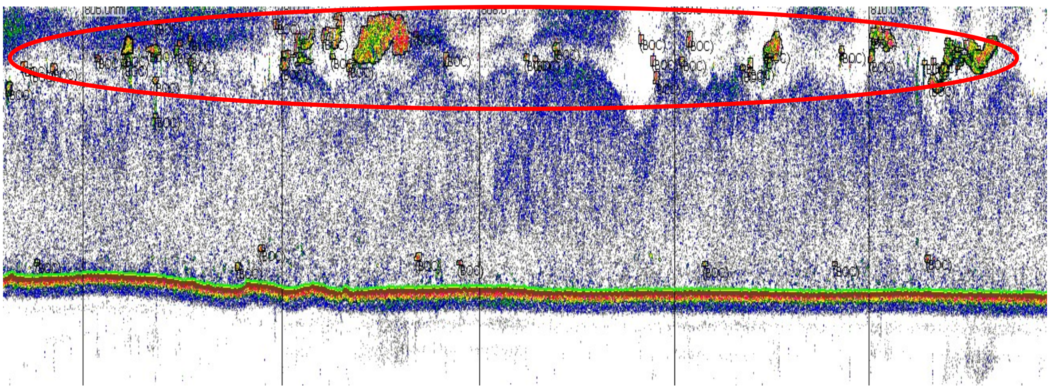
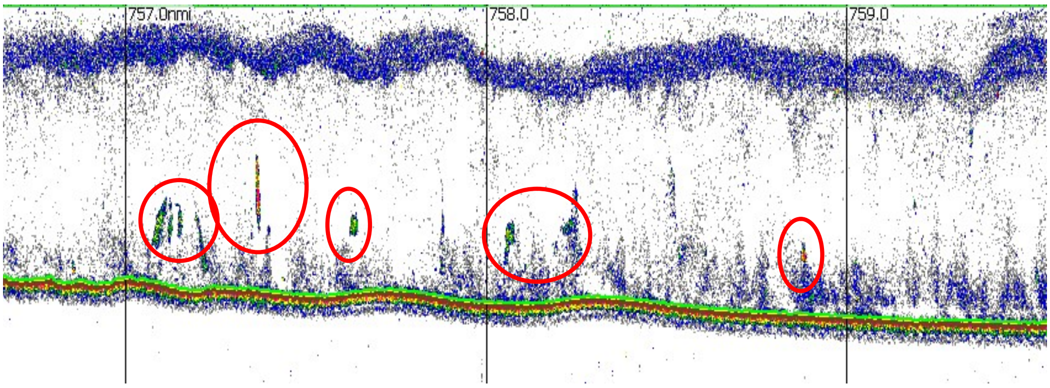


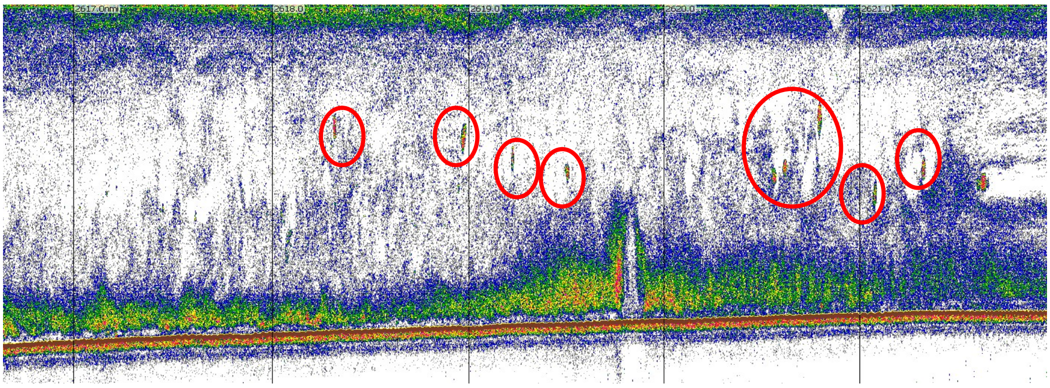
Figure 10. Length and age distribution of Celtic Sea herring within the Celtic Sea stratum (Total survey area).



a). *Southern Celtic Sea. Typical example of near surface schools (15-35 m) of immature boarfish located above the thermocline (45 m) as observed on the south of 49°N. Water depth 137m.*

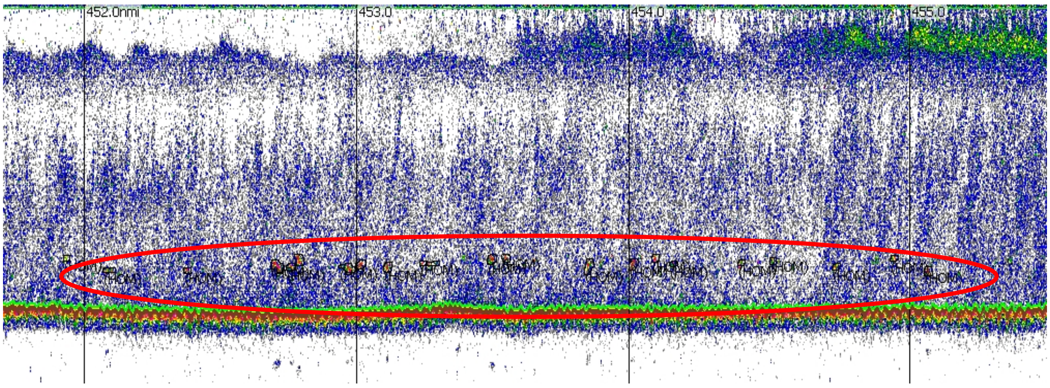


b). *Haul 05, Southern Celtic Sea. Medium density schools of mature boarfish. Water depth 148 m.*

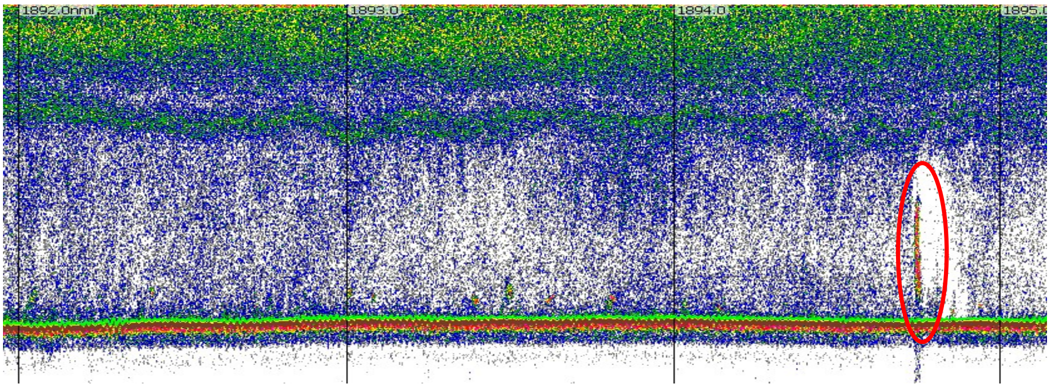


c). *Haul 16. Medium density midwater schools of mature boarfish encountered off the southwest Irish coast. Water depth 164 m.*

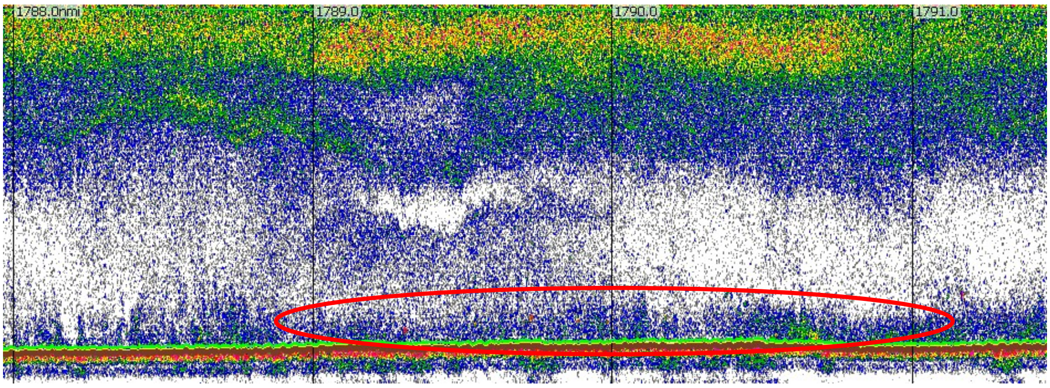
Figures 11a-l. Echotraces recorded on an EK60 echosounder (38 kHz) with images captured from Echoview. Note: Vertical bands on echogram represent 1nmi (nautical mile) intervals.



d). *Haul 3. South Celtic Sea. Low density scattering layer containing 68% of horse mackerel. Water depth 130 m.*



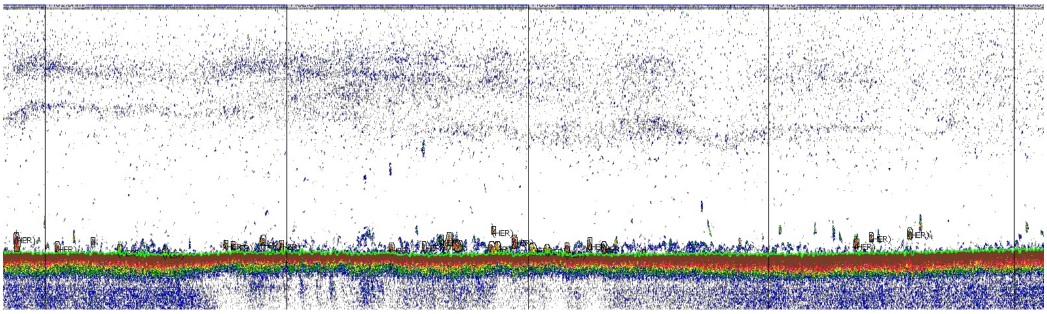
e). *Haul 13. High density single herring school located off the south coast in the western Celtic Sea, water depth 125 m.*



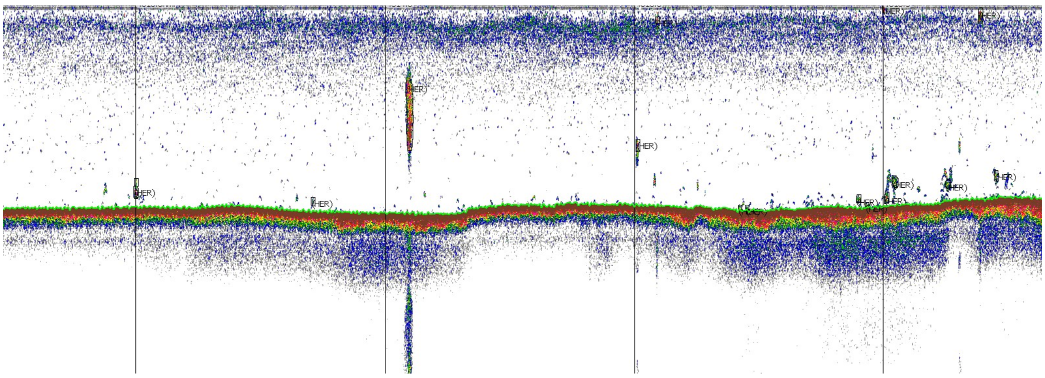
f). *Haul 12. Low density scattering layer containing herring off the south coast, Celtic Sea, water depth 110 m.*

Figures 11a-l. continued

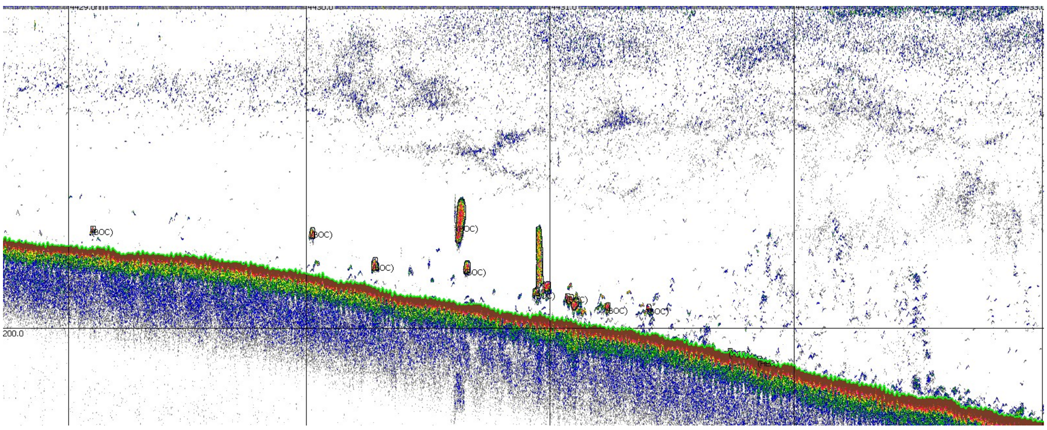
Figures11a-l. continued.



g). *Haul 26. Northwest of Tory Island, herring marks (18 kHz) along bottom, water depth 105 m.*

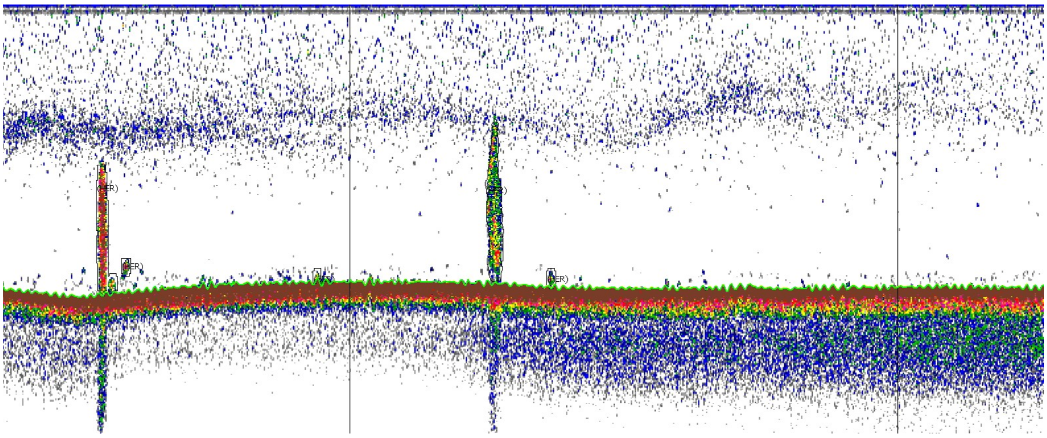


h). *North of Lough Swilly, fast moving herring marks mid-water (18 kHz), water depth 90 m.*

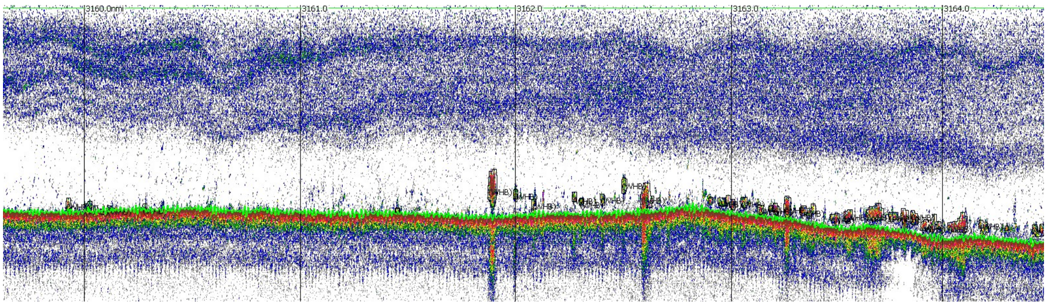


i). *West of Tory Island. Boarfish marks close to the shelf edge (18 kHz), water depth ~200 m.*

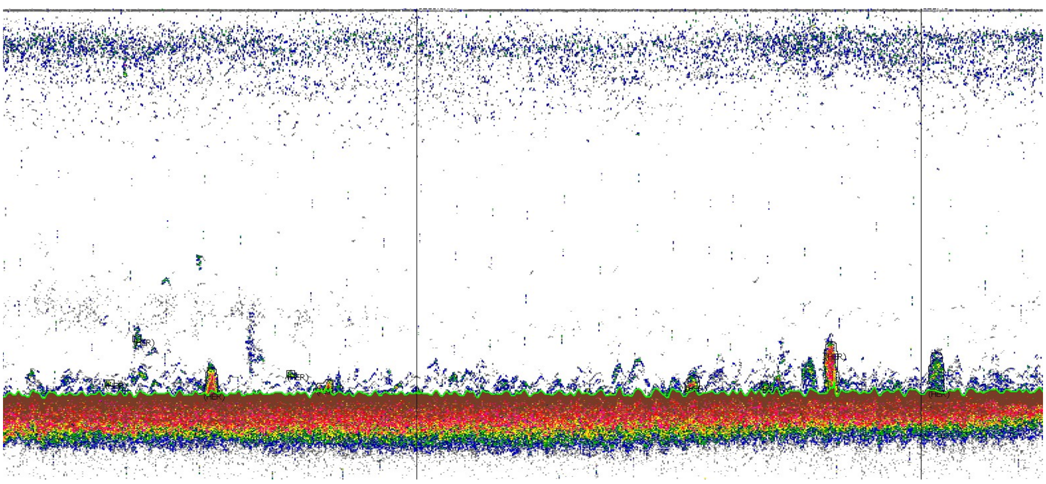
Figures11-l. continued.



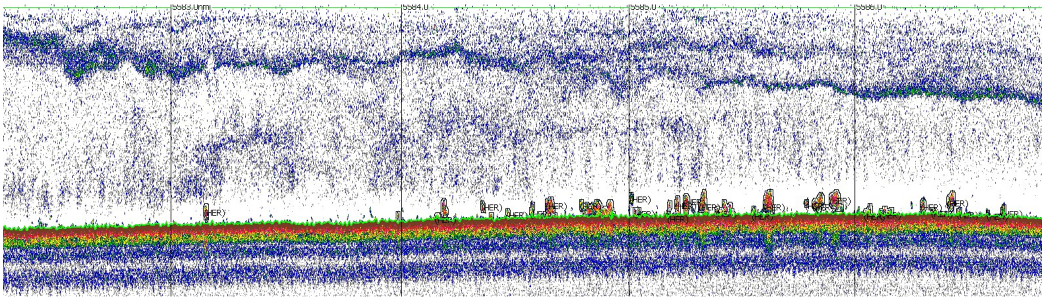
J). *Haul 27. Herring marks west of Islay (18 kHz), water depth ~70 m.*



k). *Haul 18. Juvenile blue whiting west of Slyne Head (38 kHz), water depth ~115 m.*



l). *Haul 31 South of St. Kilda. Herring marks along bottom (18 kHz), water depth ~155 m.*



m). *Haul 34 West of Butt of Lewis. Juvenile herring on bottom (38 kHz), water depth ~90 m.*

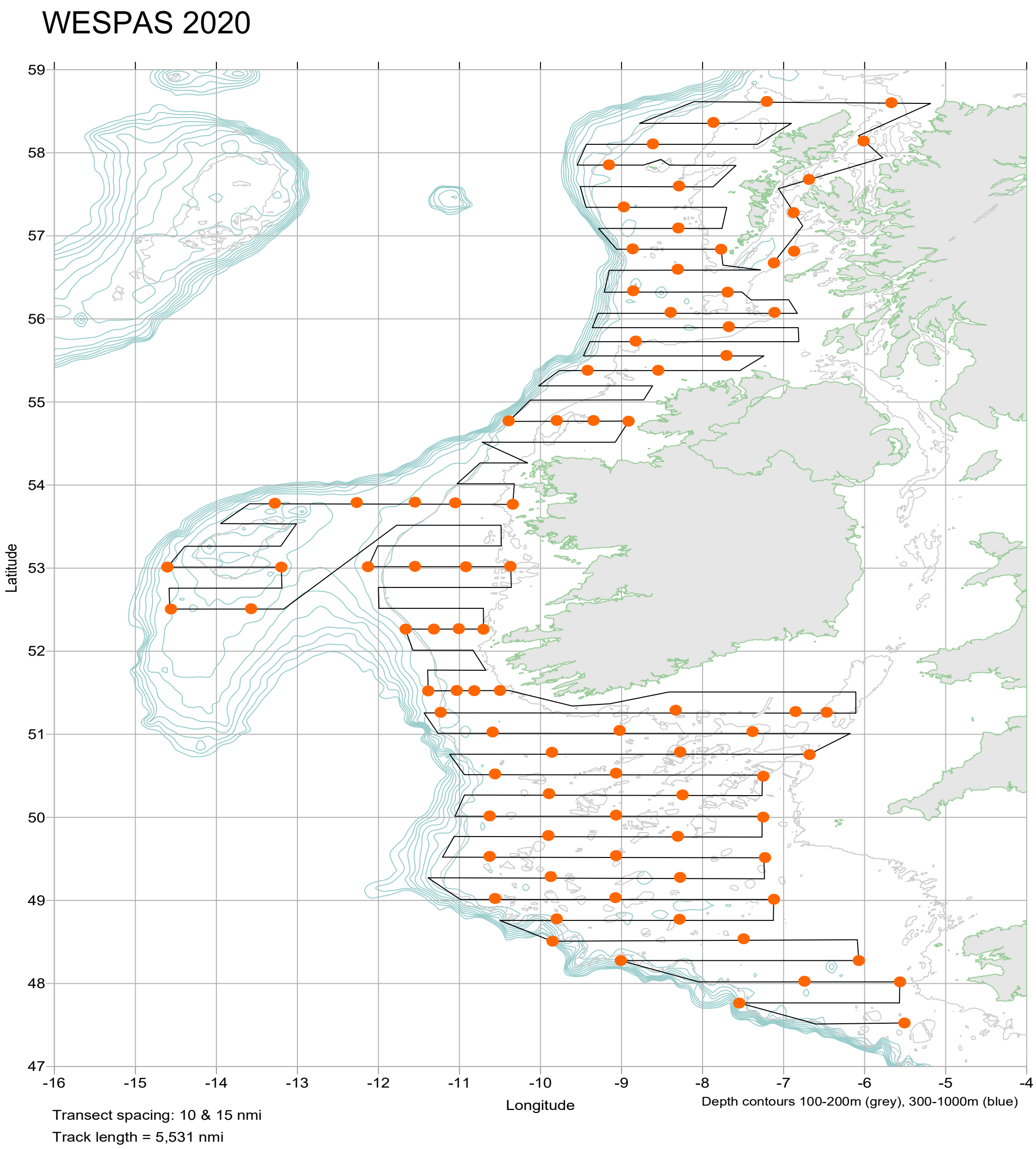


Figure 12. Position of hydrographic and co-occurring zooplankton sampling stations (n=76).

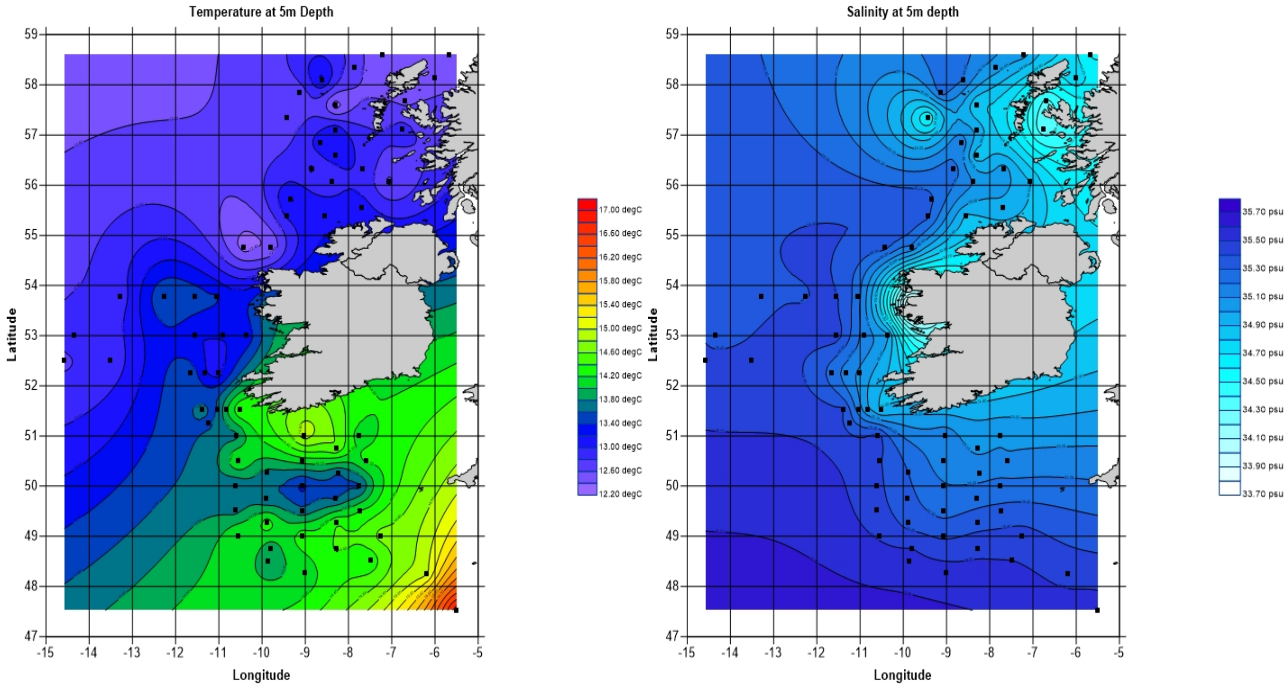


Figure 13. Surface (5m) plots of temperature and salinity compiled from CTD cast data. Station positions with valid data shown as block dots (n=76).

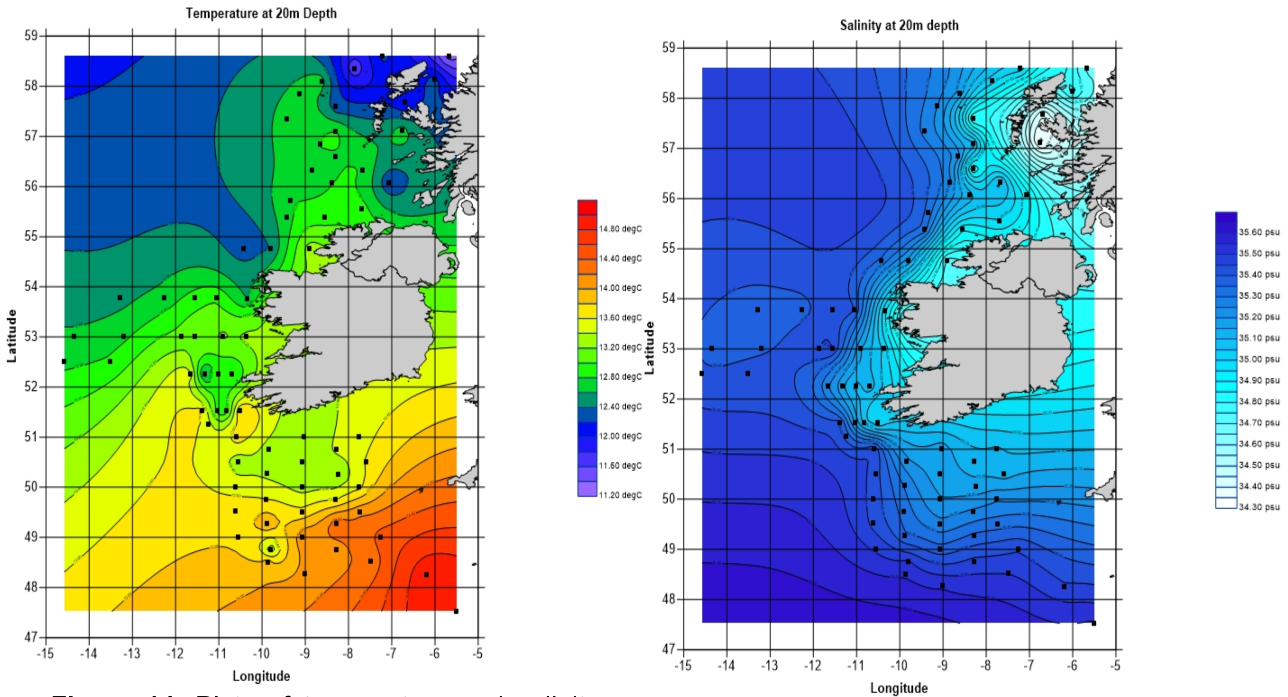


Figure 14. Plots of temperature and salinity compiled from CTD cast data at 20m depth. Station positions with valid data shown as block dots (n=76).

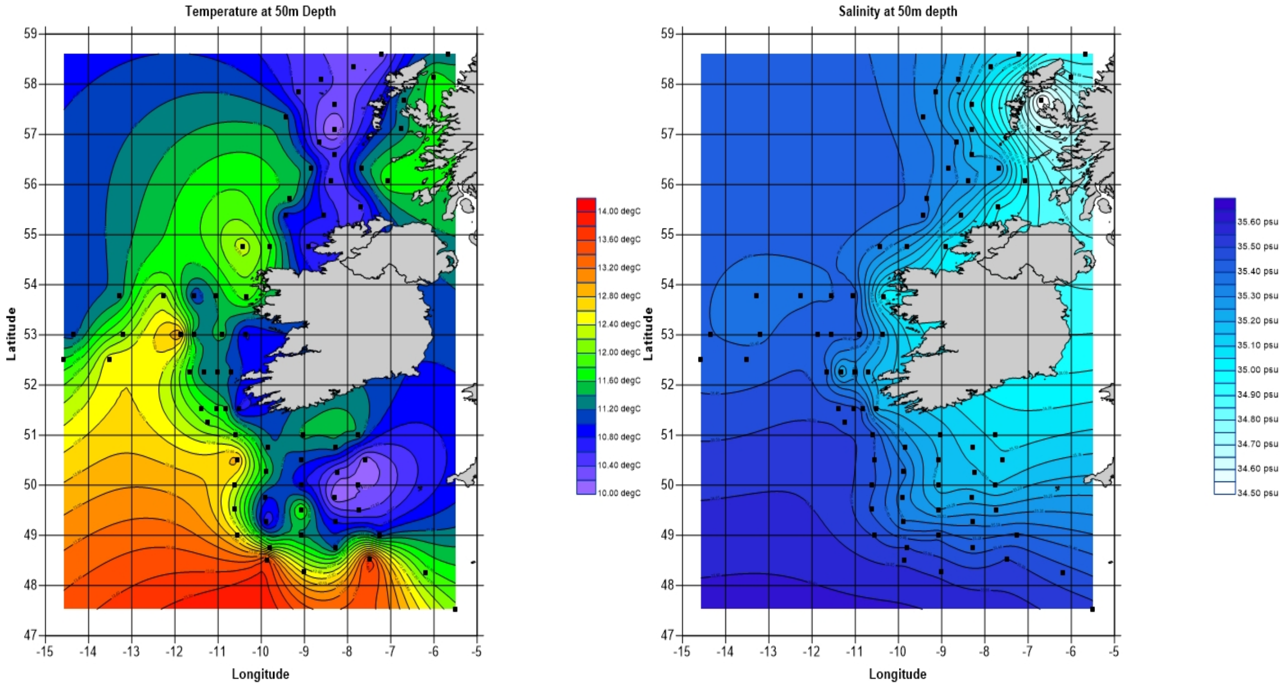


Figure 15. Plots of temperature and salinity compiled from CTD cast data at 50m depth. Station positions with valid data shown as block dots (n=76).

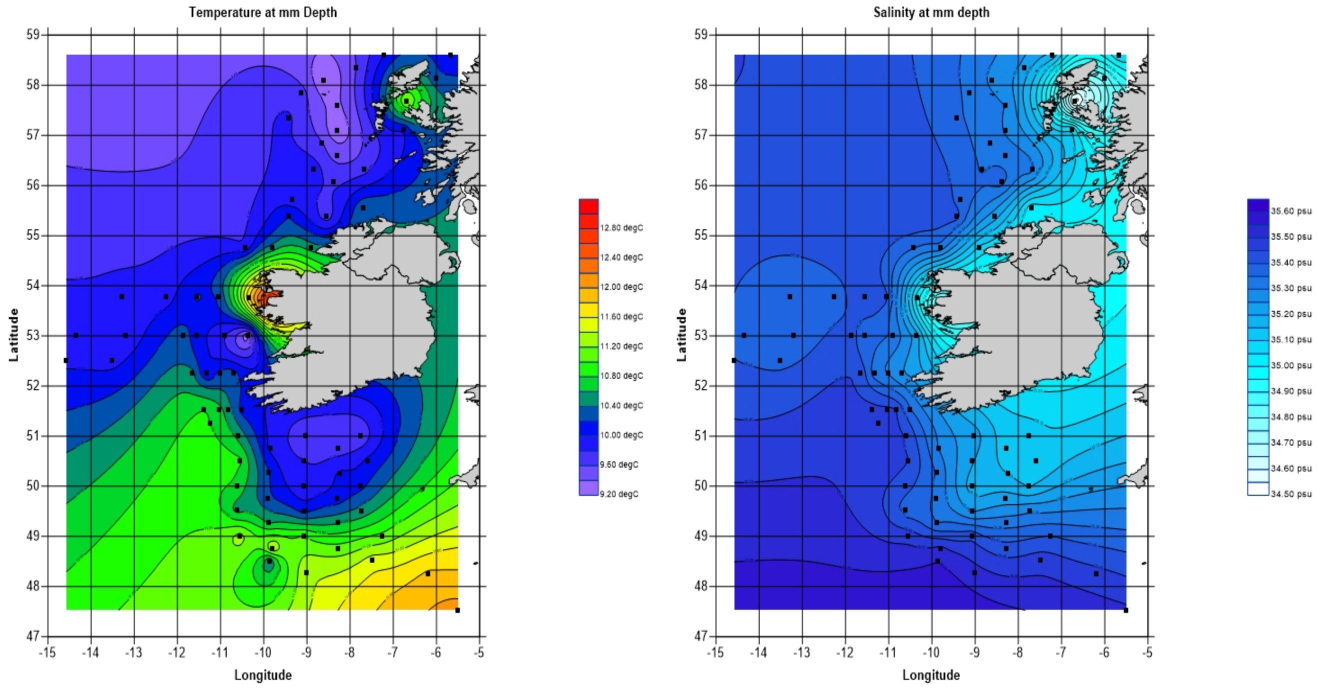


Figure 16. Plots of temperature and salinity compiled from CTD cast data at the seabed (+3-5m). Station positions with valid data shown as block dots (n=76).

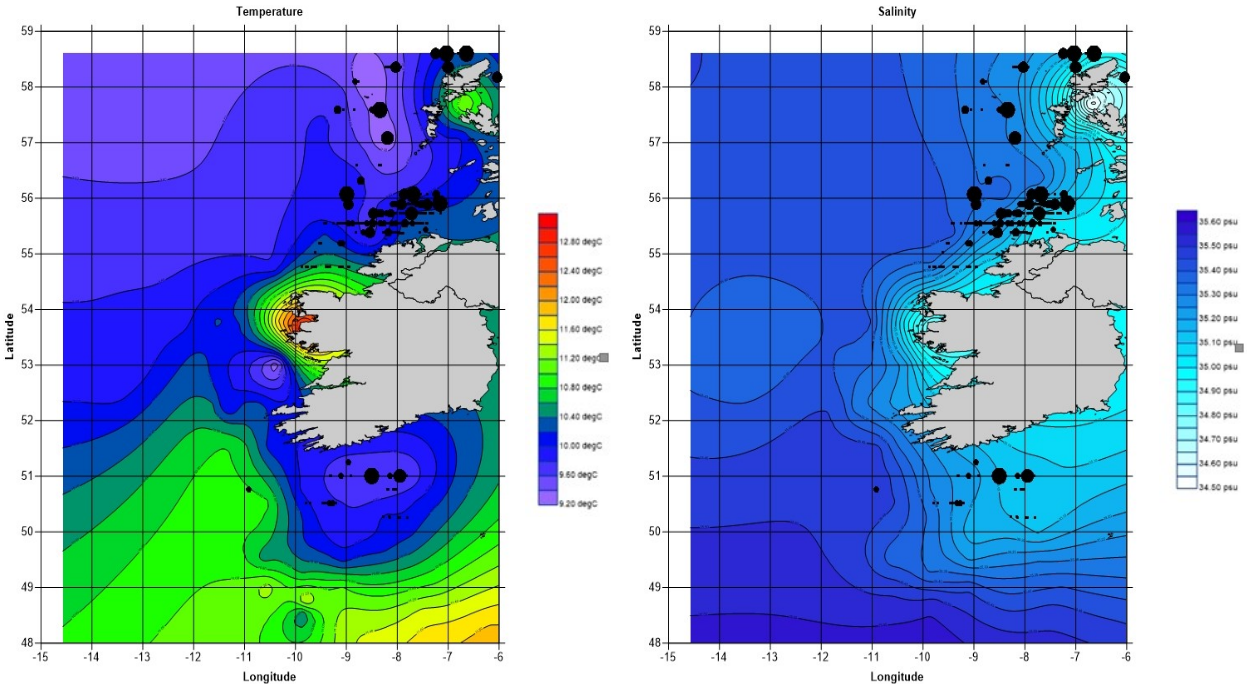


Figure 17. Habitat plots of temperature and salinity with herring distribution. Sea floor values overlaid with herring NASC values (black circles).

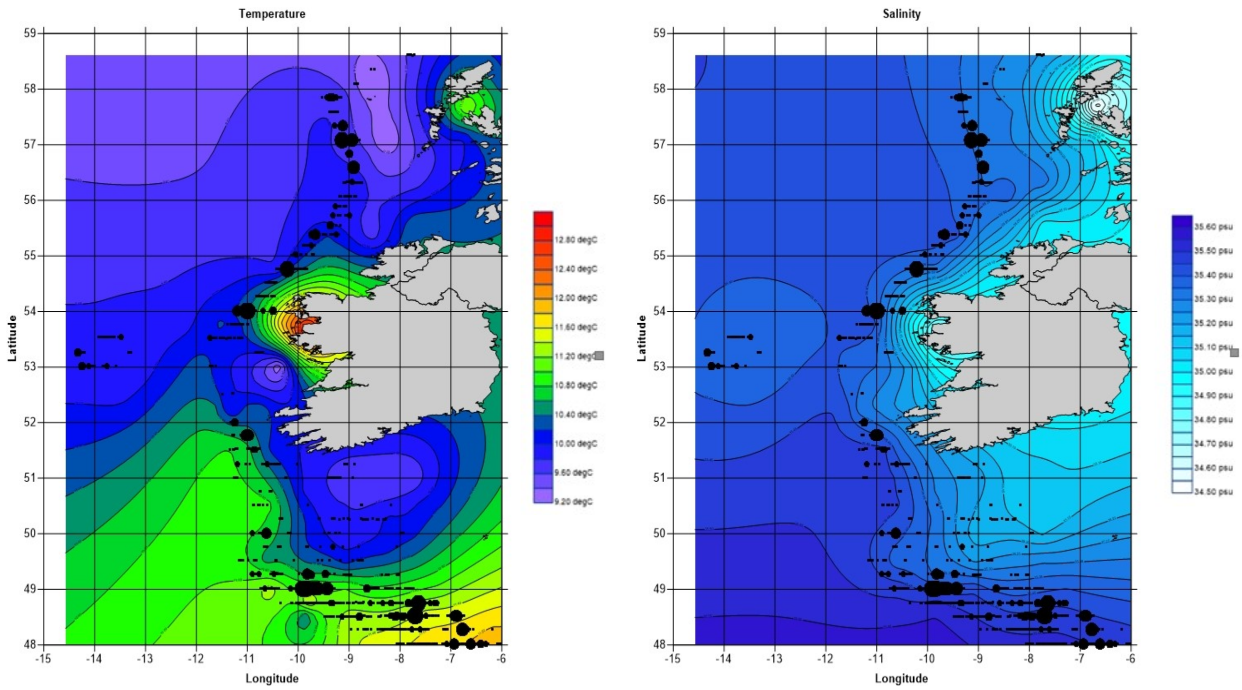


Figure 18. Habitat plots of temperature and salinity with boarfish distribution. Sea floor values overlaid with boarfish NASC values (black circles).

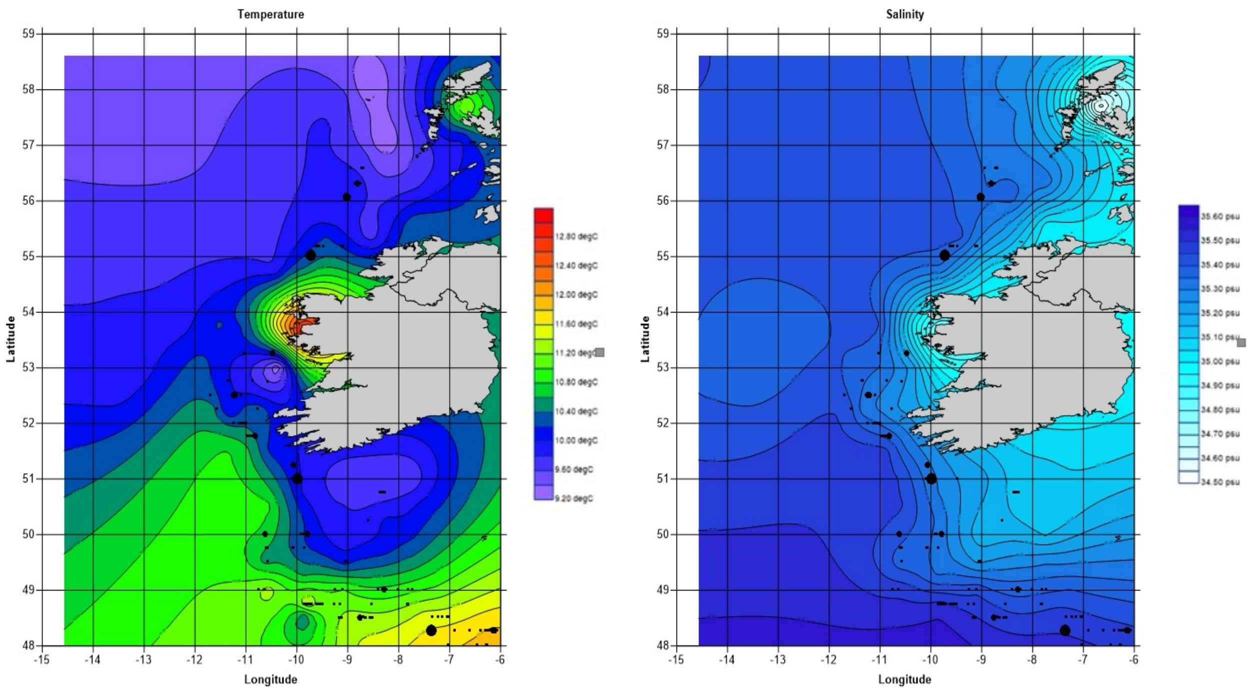


Figure 19. Habitat plots of temperature and salinity with horse mackerel distribution. Sea floor values overlaid with horse mackerel NASC values (black circles).

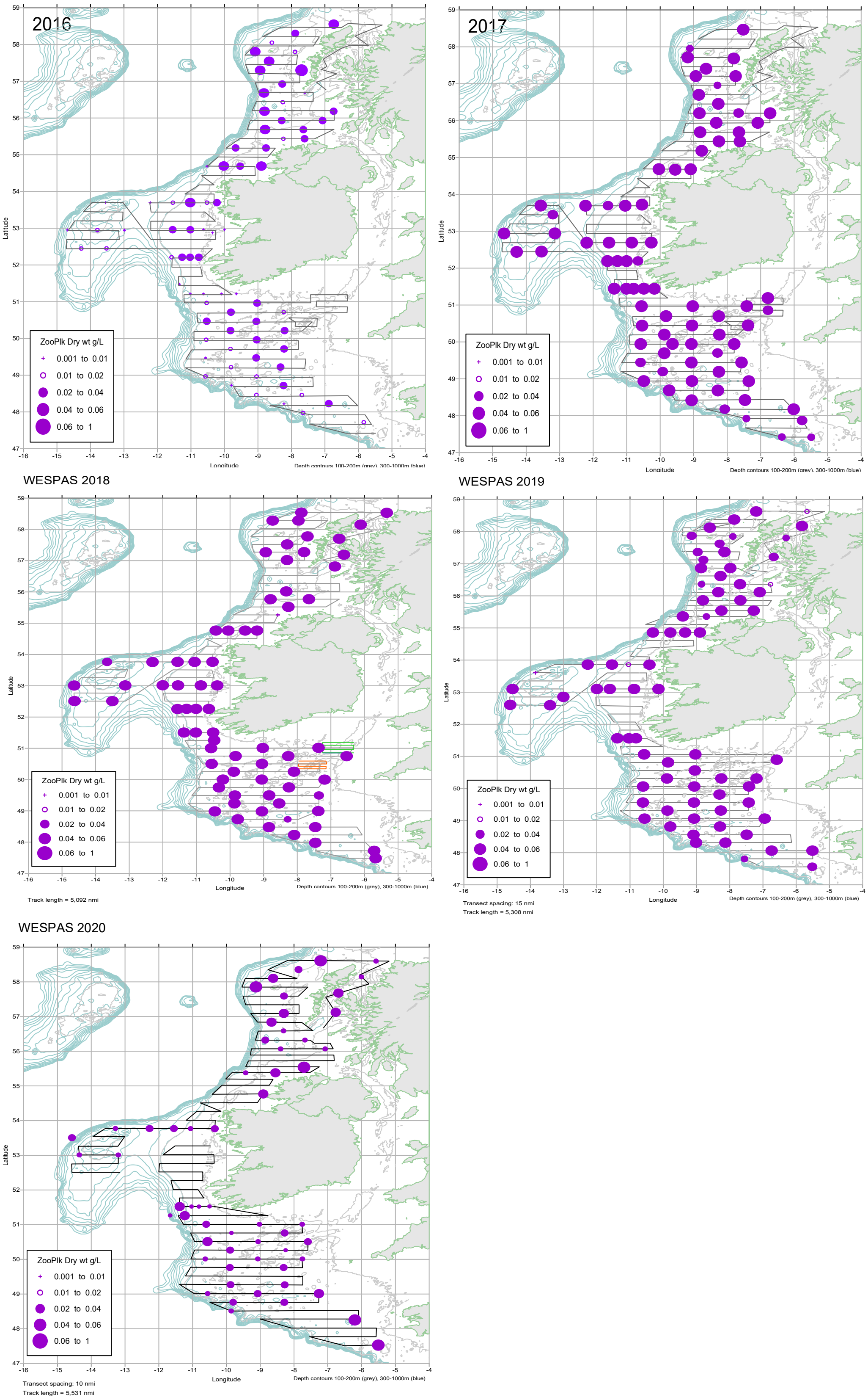


Figure 20. Zooplankton dry weight biomass by station (g dry Wt. m^3) 2016-2020.

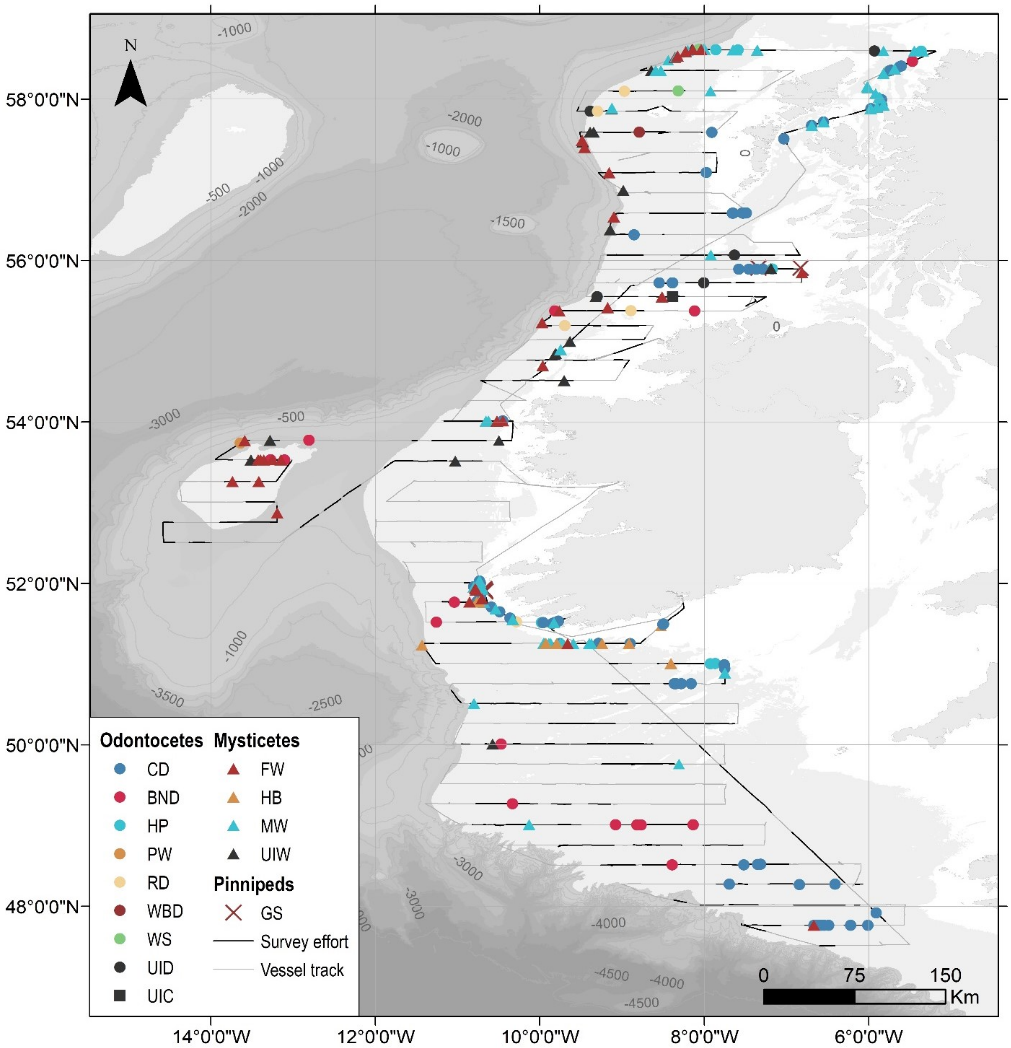


Figure 21. Sightings of all marine mammal species encountered during the WESPAS 2020 survey, represented along the track of the vessel (in grey) and survey effort (in black). Auxiliary sightings have been included. CD = common dolphin, BND = bottlenose dolphin, HP = harbour porpoise, PW = long-finned pilot whale, RD = Risso's dolphin, WBD = white-beaked dolphin, WS = Atlantic white-sided dolphin, UID = unidentified dolphin, UIC = unidentified cetacean, FW = fin whale, HB = humpback whale, MW = minke whale, UIW = unidentified whale, GS = grey seal.

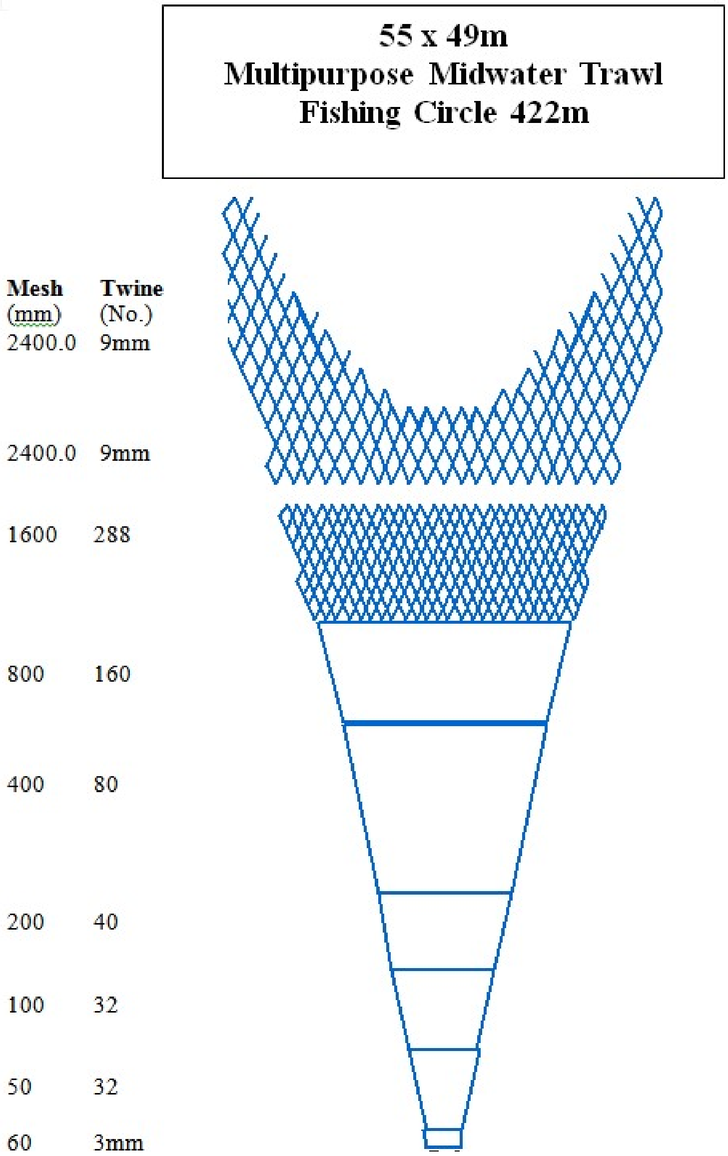


Figure 22. Single multipurpose midwater trawl net plan and layout.

Note: All mesh sizes given in half meshes; schematic does not include 32m brailer.